Report

Waihou Modelling Report

24 AUGUST 2012

Prepared for

Northland Regional Council

36 Water Street
Whangarei 0140

42071138

Project Managers:

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Jess Wallace/Justine Bennett
Associate Water Resources Engineer/Principal Environmental Scientist

URS New Zealand Limited

URS Centre, 13-15 College Hill
Auckland 1011
PO Box 821, Auckland 1140New Zealand

T: 64 9 355 1300
F: 64 9 355 1333

Principal-In-Charge:

…………………………….
John Male
Principal Hydrologist

Author:

…………………………….
Jorge Astudillo
Senior Water Resources Engineer

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Introduction

1.1 Project Background

The Priority River 2011/2012 project seeks to improve the work that was done for the Priority Rivers Flood Risk Reduction Project 2010. The Waihou River Model was found by the Northland Regional Council to be in need of improvement in order to have confidence in the flood mapping for the river's catchment.

It was identified that some critical areas needed a 2D treatment in the model for a more accurate representation of the dynamic of the flow over some large flood plains. On the other hand, as Waihou is one of the biggest catchment in the Northland Region, it was found that the SCS US method was not able to represent the hydrograph of the catchment properly, characterized by long hydrograph recession limbs that contain large volumes. As part of this modelling work, together with the modelling improvement there was an analysis of the hydrological model and a non-linear method was used.

Additionally, as a qualitative analysis, a number of flood debris level points were compared against the verification and design events.

Other than these modifications, the rest of the model stayed the same as the 2010 version, with the same verification event, design events rainfall, rain profile and areal reduction factor.

1.2 Catchment Description

The Waihou River drains to the head of the Hokianga harbour as shown in Figure 1-1 . The Waihou catchment consists of six main tributaries:

- Waihou River: Main river merging with the Hokianga harbour.
- Waipapa River: Coming from the north-east and discharging into the Waihou River.
- Whakanekeneke Stream: Coming from the east and discharging into the Waihou River.
- Mangapa River: Coming from the north and discharging into the Waipapa River.
- Whakateterekia Stream: Upstream extension of the Mangapa River and start of the longest catchment length.
- Kauriwhati Stream: Eastern catchment draining into the Waima River.

Topography

The Waihou River River catchment is approximately 279 square kilometres. The longest stream path is approximately 42 km in length. The upper catchment is predominantly steeply sloped forested terrain slopes of 20-40%. The stream gradients in the main upper tributary reaches are generally an average of 0.5%. This suggests these streams are well stabilised. The smaller tributaries have steep gradients before they join the main streams. The forested areas discharge to the Waihou River in the lower catchment.

The lower 9 km of river is extremely flat with stream slopes of less than 0.4% and the predominant land cover is grassland. The floodplain in this area is relatively wide at 1.5 km, for a Northland catchment, but it gets narrower as it goes upstream.

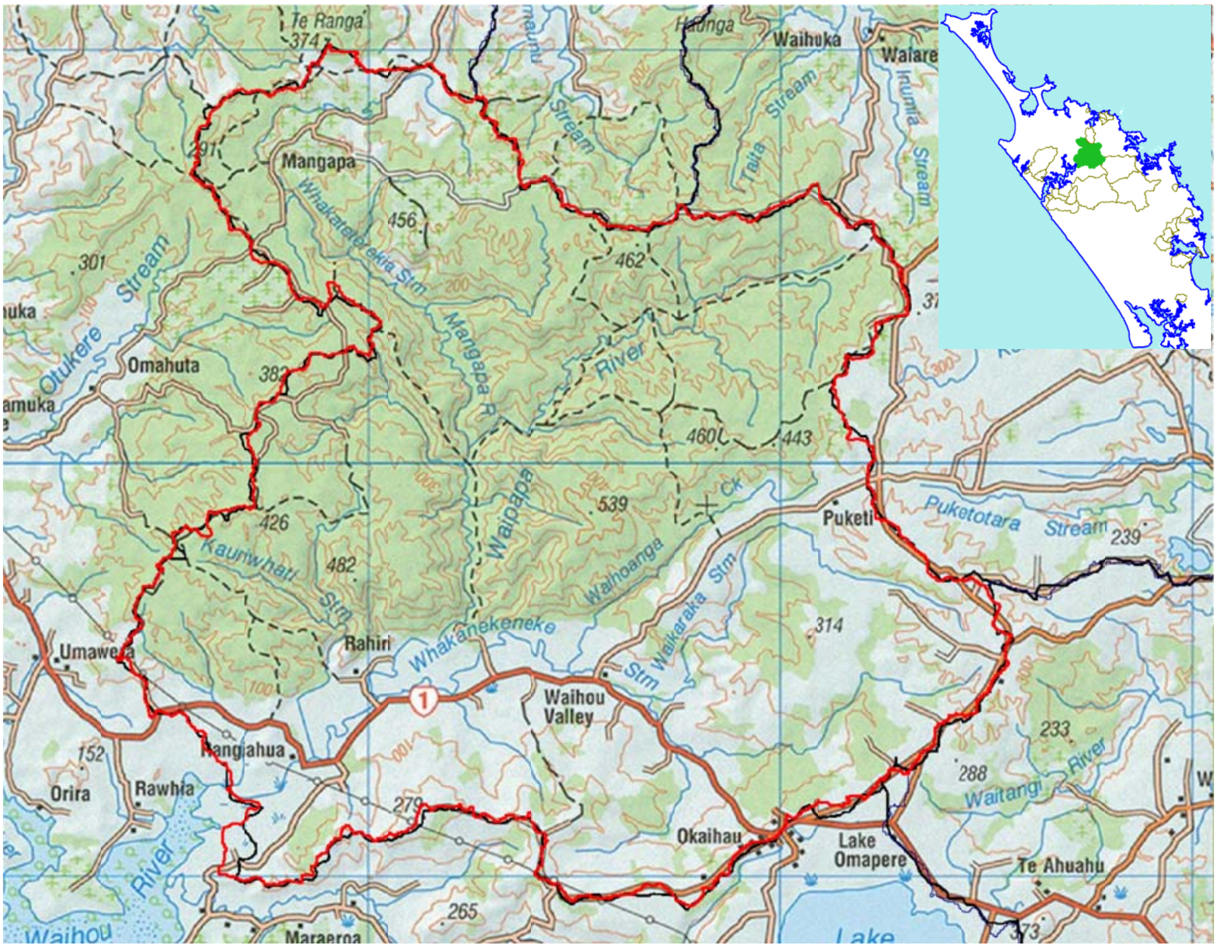
1 Introduction

Notable Features

State Highway 1 runs through the southern portion of the catchment, from Okaihau in the east, to Rangiahua in the west. There are also some other notable features within the Waihou River catchment, the most important are listed below:

- Cemetery located on both sides of Rahiri Road at the conjunction with Harris Road.
- The NRC GIS database contains records of archaeological and recorded cultural heritage sites within the Waihou River catchment.
- Omahuta Forest and Puketi Forest occupy the northern portion of the catchment. Numerous tracts of native bush are scattered throughout the catchment.

Figure 1-1 A general location plan of the Waihou catchment and tributaries



1.3 General Modelling Approach

The present project work continues the modelling methodology explained in the NRC Priority Rivers Modelling Report, Feb 2010. This modelling report is prepared as a supplementary report to the NRC Priority Rivers Modelling Report, Feb 2010. GIS and integrated modelling are central to the modelling methodology. This method provides a comprehensive model, more accurate outputs and the ability to be continually upgraded.

1.4 Modelling Scope

This work package included the gathering of more information about recorded flood levels in the Waihou catchment and/or expected levels where records are available, especially in the lower catchment where levels seem to be underestimated. The modelling tasks include an analysis of pertinent data and evaluation of the non-linear reservoir hydrological model. Some critical storage areas were turned into 2D areas using a low resolution mesh.

No additional survey was included in this work.

Modelling Objectives

The general objective of the model improvement was to increase the accuracy of the model results in comparison to known flooding and gauged flood events. The main objectives were as follows:

- Analysis of flood level data,
- Review the hydrologic model and use the non-linear reservoir model,
- Rerun the verification event of March 1988,
- Rerun the design storms for the new calibrated model, and
- Generation of new flood maps.

Issues identified during model improvement and calibration

- Additional storage areas required
- Adjustment of manning values required
- Redistribution of runoff from sub-catchments into critical areas required.

Data Collection and Data Analysis

2.1 Data Collection

NRC provided URS with a set of data to improve the model and to run the verification event of January 2011. The data received is listed and described below:

- Flood Levels for 2003
- Flow/Levels series March 2003 Waipapa River Forest Ranger
- Flow/levels series Jan 2011 Waipapa River Forest Ranger
- DXF (flood model)
- Flood levels for Jan 2011
- Contours plan (pdf)

2.2 Data Processing and Analysis

2.2.1 Survey data process and other GIS tasks

As per the methodology, modelling tasks were assisted by GIS. Flood points were processed on GIS before being imported into the IWRS model, and other calculations, such 2D break lines and sub-catchments re-delineation, were also assisted by GIS.

2.2.2 Surveyed Debris Flood Levels

The results of this model were compared against flood levels available for Waihou catchment for the events of March 2003 and January 2011 to provide a more holistic understanding and a comprehensive analysis of the flood extents. Below is a general comparison of the 3 events:

- March 1988 rainfall was about 155mm in 24hours, which is close to a 2yr 24hr event. The maximum tide level was about 2.35mOTP
- March 2003. No specific details are available for this event in the Waihou catchment.
- January 2011 rainfall is estimated to be between 150mm to 200mm with an approximate duration of 16hours, which would place it close to a 10yr event. The tide level is not available for this event in Waihou catchment.

As the verification event of 1988 seems smaller compared with the ones in 2003 and 2011, it is more appropriate to compare the available debris flood levels with the 10yr 24hrs design event. These results will be presented in Section 4.2 of this report.

2.2.3 Verification Event Analysis

The scope of this work included a re-run of the verification event. The verification event for the first stage of Waihou catchment was the storm event of March 1988. However, the catchment only has one level/flow gauge at Waipapa at Forest Ranger and that is located outside of the LiDAR area.

This verification event was re-run for the new improved 2012 model with the changes that will be explained in the Section 3 of this report.

2.2.4 Rainfall distribution for the Verification Event

The rain series for the verification storm of March 1988 were kept unchanged from the previous model set up.

2.2.5 Flow/Level gauges analysis for Verification Event

There is only one flow/level gauge available at Waipapa at Forest Ranger. This Stage/Flow station is located outside of the available LiDAR area. Due to this, all cross sections were assumed with a trapezoidal shape based only in the 20m contours and aerial. Levels and slope are based also in the 20 m contours (as for the previous model set up). For that reason, levels in this area are not accurate so are not considered for this validation. Never the less, since the model level results in this location are available, they are shown alongside the other verification results.

3 Modelling Methodology

3.1 Previous IWRS Model Analysis

As part of the first stage of NRC Priority River Models a model of Waihou catchment was built and validated. The previous model developed by URS is the starting point of this work.

In general the previous model was stable and well defined in many areas; however, a few critical storage areas need to be turned into 2D with an appropriate resolution to improve the model results.

The following is a description and analysis of different features that were used to improve the model.

3.2 Storage areas into 2D Polygons

One storage area that was located in a large flood plain with strong slopes was turned into a 2D area; this was done to improve the description of the flood in that area. Break lines were added to enforce the generation of a small resolution mesh along streams and channels present in this area. Figure 3-1 shows the details of the modification.

3.3 Flood Compartment

Flood compartments are necessary to interpolate model level results into a water surface and generate the flood maps over the LiDAR ground model. Improvements in the flood compartments were done in some areas for a better description of the flood maps. These improvements mainly cinist of re-shaping of the flood compartment polygons to make sure they cover the flooded area and that the interpolation features are taken from appropriate surrounding objects.

3.4 Hydrological Model

Part of the scope of this work was to re-run verification event for Waihou catchment with an alternative and more suitable hydrological model. URS tested the use of a non-linear reservoir method for the routing of the hydrological model instead the US SCS method used in the 2010 model.

The following sections provide a brief description of these methods and their relative advantages.

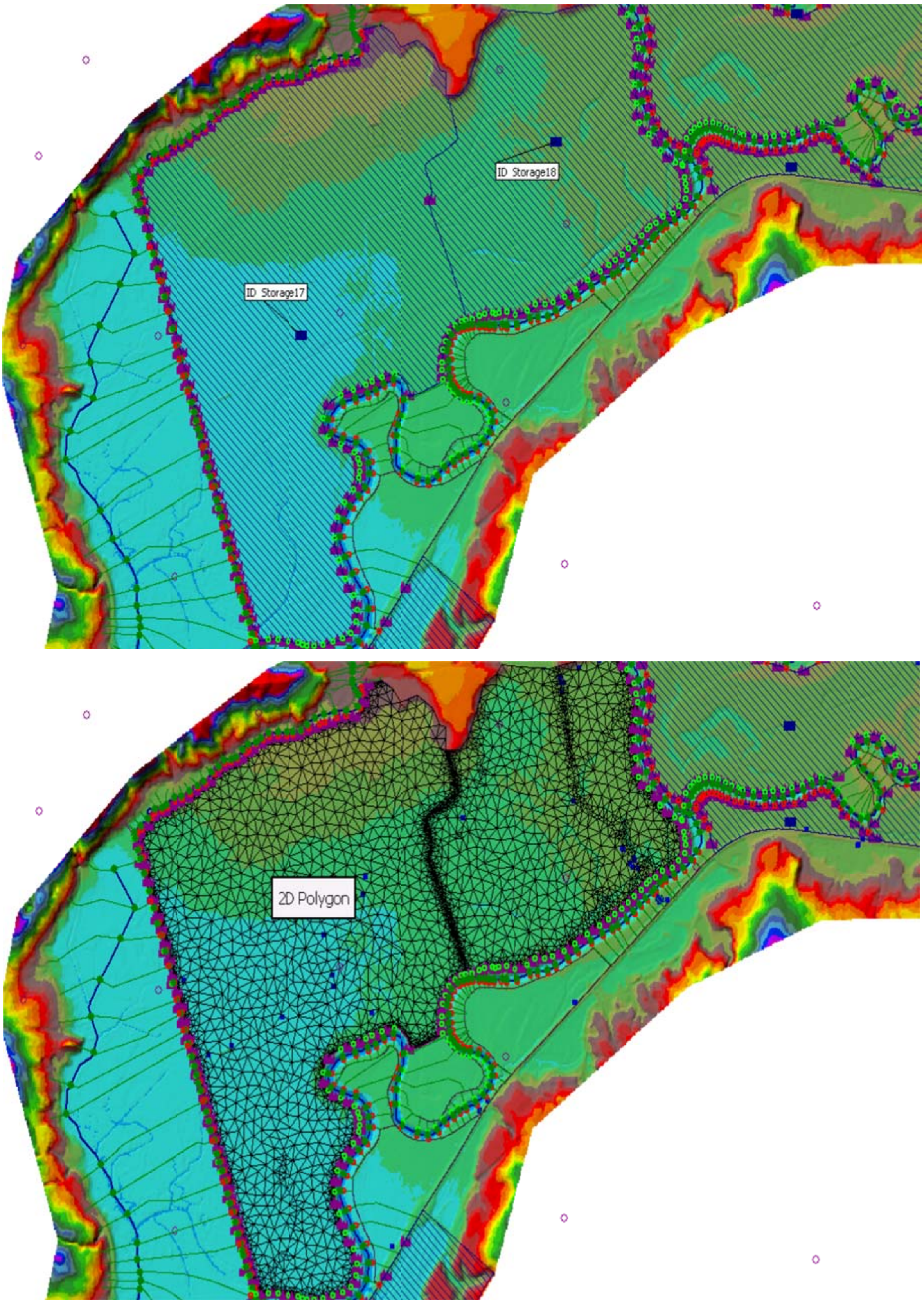
3.4.1 US SCS Method

The previous Waihou model used an US SCS unit hydrograph method as the hydrological model. A CN value was to be derived for each sub-catchment based in the land-use. The main concern with the use of the US SCS method for the Waihou catchment is that in general, the peak and volumes cannot be calibrated simultaneously, as the unitary hydrograph is invariable. Another alternative is the Snyder unit hydrograph which allows a better control of the peak and base time. From experience in NRC models and other catchments in New Zealand we have found that the US SCS method is not satisfactory and does not represent the hydrologic behavior of large urban catchments.

Further experience and analysis in NRC catchments, as well as other catchments, suggest that a better and more versatile alternative is the use of the non-linear reservoir method to simulate the sub-catchments runoff.

3 Modelling Methodology

Figure 3-1 Previous storage area and new 2D mesh



3.4.2 Non-Linear Reservoir Method

The non-linear reservoir method consists of representing each sub-catchment as a reservoir with a non-linear discharge. Two parameters are required to calibrate the shape of the hydrograph, K and p, where K is the proportional coefficient and p is the exponential coefficient.

$$V(t) = K \cdot Q(t)^{p}$$

Where *V* is the storage volume in the reservoir, and *Q(t)* is the flow or runoff from the sub-catchment.

Then, the volume balance defines a differential equation to solve the function *Q(t)*.

$$\frac{dV}{dt} = K \cdot p \cdot Q(t)^{(p-1)} \cdot \frac{dQ(t)}{dt} = I(t) - Q(t)$$

The previous differential equation cannot be solved analytically unless *p=1.* This equation is solved numerically by InfoWorks RS over each sub-catchment to obtain its respective runoff as a response to a given rain series *I(t)* as intensity.

Parameter *K* can be estimated based on catchment features such as length, slope and land cover. Those are available for all Waihou sub-catchments.

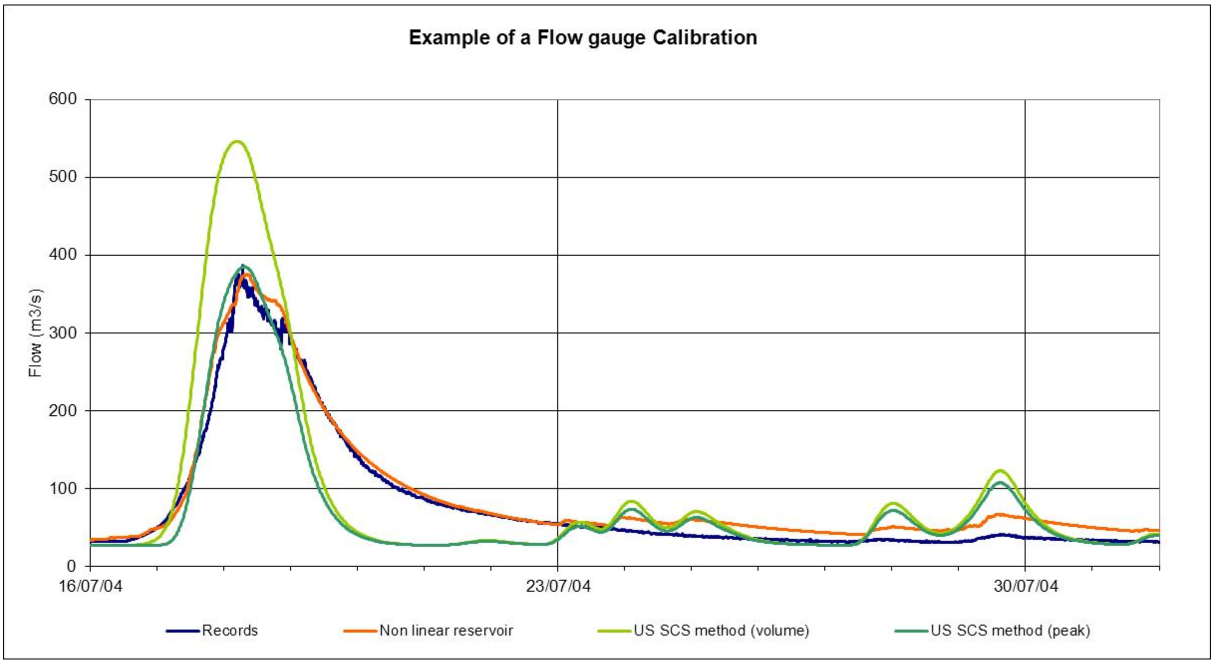
It is important to note that a non-linear reservoir method does not allow a good representation of the initial losses and uses a constant infiltration rate. However, because the purpose of this modelling work is to calibrate and model big storm events (over 10yrs), the initial losses are not critical as they are consumed by the storm very shortly after the rain starts.

The key benefits of this method are its versatility representing a large range of hydrographs shapes, and a better definition of the slow response for large sub-catchments.

3.4.3 Comparison of Hydrological Modelling Approaches

Figure 3-2 shows a comparison between the US SCS method (applied to calibrated peak and volumes separately) and the non-linear reservoir method (to calibrate both peak and volumes). This example is taken from another catchment in New Zealand (Whirinaki at Galatea station, Rangitaiki river catchment, Bay of Plenty). The figure shows that the hydrograph generated from the non-linear reservoir more closely matches the actual flow gauge records than either of the US SCS method variants and hence the Non-Linear method was selected for use in this catchment.

Figure 3-2 Example of a flow gauge calibration using different hydrological models



3.4.4 IWRS Non-Linear Reservoir parameter

Infoworks has a non-linear Reservoir hydrological model implemented as part of boundary conditions alternatives. Volume parameters can be defined whether using a runoff coefficient or an infiltration rate in mm/hr. Tests were done to assess their advantages and limitations.

The infiltration method was used as it offers a better description of the rain losses for big events, and it showed partial advantages over the runoff coefficient method.

The hydrograph shape is controlled by the parameters K and p shown in the previous section. These parameters will be estimated to shape the hydrograph to find the best match for volume, peak and tail flows.

If required, the non-linear method can also allow the input of a base flow for each sub-catchment.

3.4.5 Constant Infiltration Rate

There is an important difference between the methodology used previously with the US SCS method based on CN values, and the current approach with the infiltration rate with the non-linear reservoir method. The CN value was previously defined for each sub-catchment based in local land use; the current methodology has instead selected a unique infiltration rate to be applied over the whole catchment. This infiltration rate was estimated based on the rainfall and flow records for the event of January 2011.

3.4.6 Base flow and Infiltration Rate

There was limited information to estimate a reliable base flow to be estimated for each sub-catchment. The only available information was from the Waipapa at Forest Ranger station records that show a base flow of 0.693m^3/s through this gauge before the rain started. This information was used to estimate a base flow density that was calculated to be 0.057l/s/ha. This base flow rate was distributed uniformly over the whole catchment to assign the base flow for the verification storm.

Infiltration at saturation conditions was found to be around 1mm/hr for the verification event. This infiltration rate refers to the infiltration that happens under saturation conditions.

The base flow and infiltration rate will change for each scenario, and were chosen with care to ensure a well-defined scenario considering different levels of soil moisture and the appropriate rain season.

3.5 Model Parameters

The verification event of March 1988 was re-run with the modified 2012 model of Waihou catchment that included some extra 2D polygons, storage areas and a non-linear reservoir method for the hydrological model.

Table 3-1 below summarizes the variables reviewed on the verification event:

Table 3-1 Verification parameters

Variable	Value
HYDRAULIC MODEL	
Manning	
Main channels	0.030 - 0.065
Flood plains	0.050 - 0.07
2D polygons	0.050
HYDROLOGICAL MODEL	
Non-Linear Reservoir	
K =	5.0
p =	1.0
Infiltration Rate (mm/hr)	1.0
Base flow (lts/s/ha)	0.057

3.6 Design Events

The design event was kept the same as from the previous 2010 version of the model, that is a 24 hour storm with a Northland rain profile defined in the Hydrological Report of the Priority Rivers Project 2010. As a summary of the previous set-up, the design events simulated with the new 2012 Waihou model have the following features:

1. The spatial distribution of the rain was applied using the Hirds V3 distribution. In the previous mode this was applied as a factor between 0 and 1 over the US SCS hydrographs of each sub-catchment. For the Non-Linear reservoir method used in the 2012 model, this factor was applied directly over the rain series. The nominal rain depth adopted is the maximum that corresponded to a factor of 1.0. For more details of this methodology refer to the NRC Priority Rivers Modelling Report, Feb 2010.

2. No areal reduction factor (ARF=1.00) as agreed with NRC.

3. Two ARI events are simulated: 100yr plus climate change; and 10 year. Table 3-2 shows the rain depths for the 24 hour duration storms.

3 Modelling Methodology

Table 3-2 Rain Depths for 24 hour Storms

Design Storm	24 hrs Average rain depth (mm)	24 hrs max rain depth (mm)	24 hrs min rain depth (mm)	[24 hrs average rain depth] x ARF (mm)
Distribution factor	0.901	1.000	0.744	-
ARF	-	-	-	1.00
ARI 010	193.9	215.3	160.1	193.9497
ARI 100F	368.3	408.8	304.0	368.2897

4. The same rain pattern is used as in the previous NRC Priority Rivers work. For more details refer to NRC Priority Rivers Modelling Report, Feb 2010.
5. The level boundary conditions are taken from the previous model as the 2yr tide level that is applied over the 10yr design event. A surcharge of 0.5m is applied over the 100yr with the climate change event to take into account the sea level rising.

As mentioned in Section 3.4.6 the base flow and infiltration rate will change for each scenario, and they need to be chosen considering different level of soil moisture. For the design events scenarios it was considered a null base flow and a constant infiltration rate of 1 mm/hr. A discussion of this and other issues is provided in Section 5.

The new Waihou model was then run under these design events scenarios and flood maps produced. Final flood maps are included in Appendix A.

4

Modelling Results

The verification results are shown below against their respective flow records. Additionally, the design events are compared with the 155 flood points available for the events of March 2003 and January 2011. As explained in Section 2.2.2, these events registered intensities around the 10yr design event.

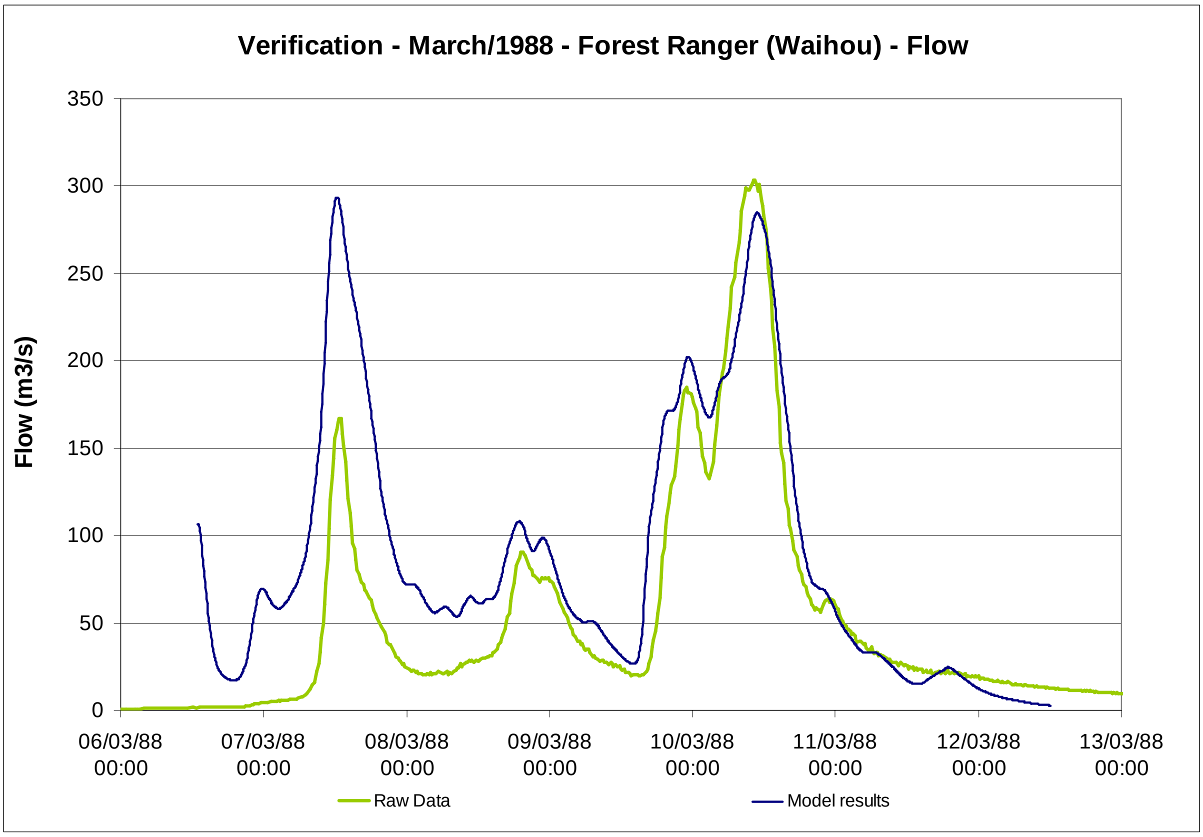
Results are compared against flows at Waipapa at Forest Ranger. Additionally, flood levels are compared against flood levels measured for the storm of March 2003 and January 2011.

4.1 Verification Results

Following are results of the verification results against available records.

Waipapa at Forest Ranger

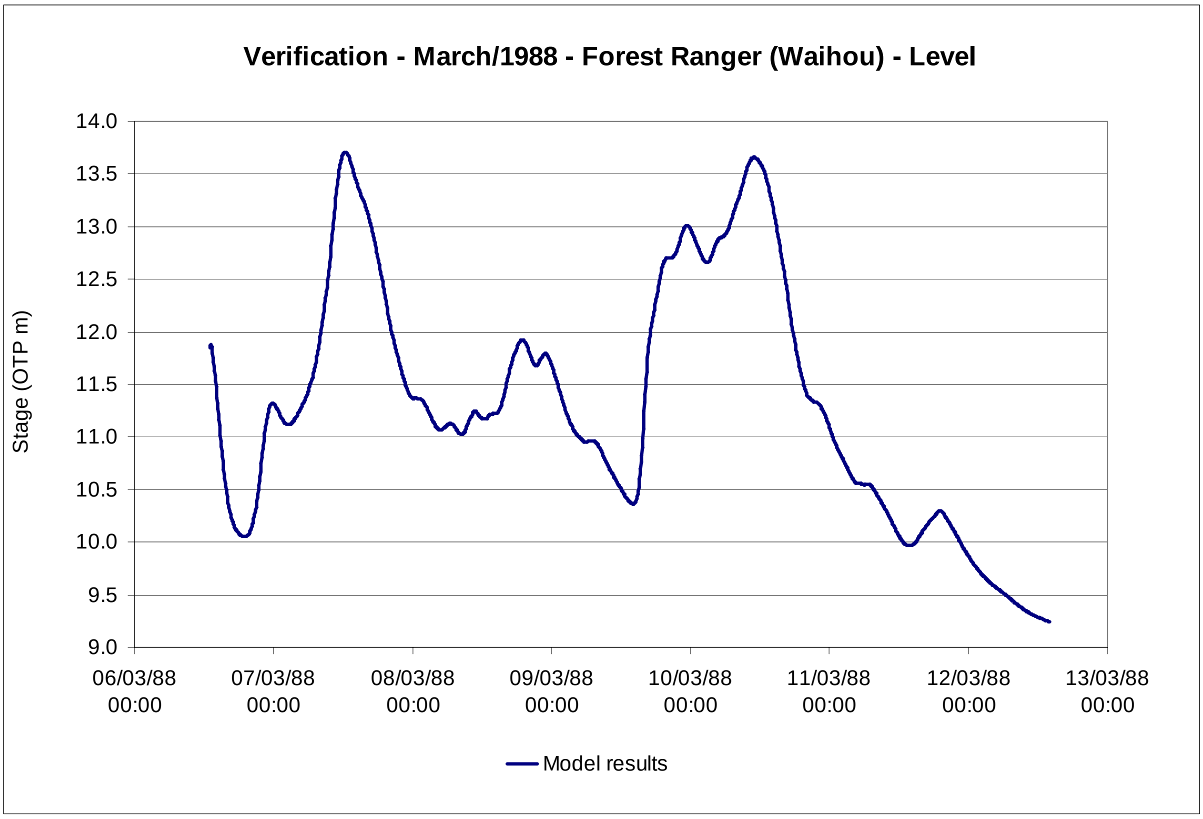
Figure 4-1 Recorded and modelled flows at Waipapa at Forest Ranger station



The model was calibrated to provide a good correlation in a saturated condition. In the graph the first peak is overestimated as the infiltration rate is considered in saturation during the whole storm, whereas in reality the first peak happened under high infiltration conditions. The second peak presents a good correlation as it corresponds to saturation conditions after 24 hours of heavy rain.

4 Modelling Results

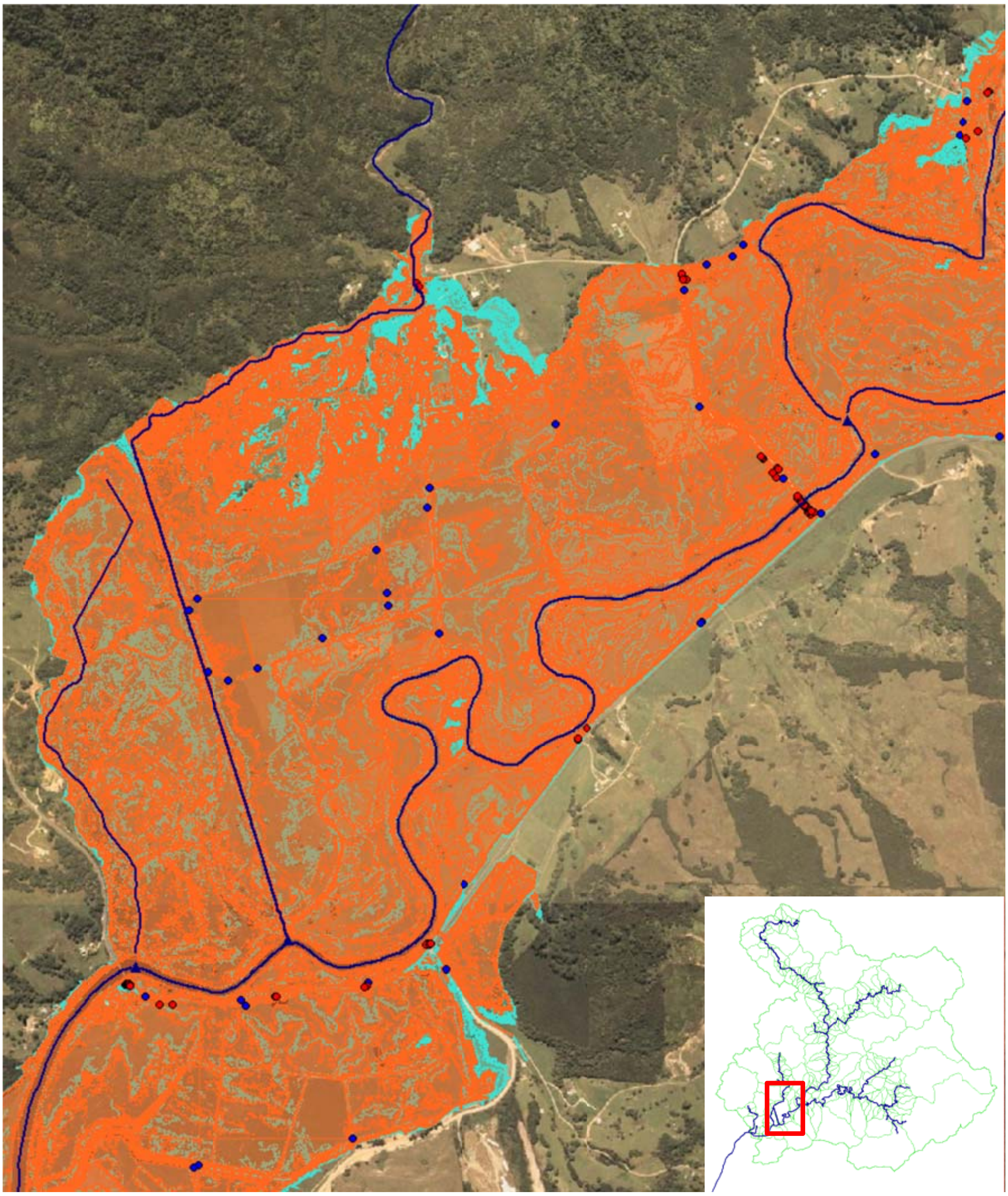
Figure 4-2 Modelled levels at Waipapa at Forest Ranger station (records with no known datum to compare against and gauge outside of LiDAR data)



4.2 Design Events Analysis

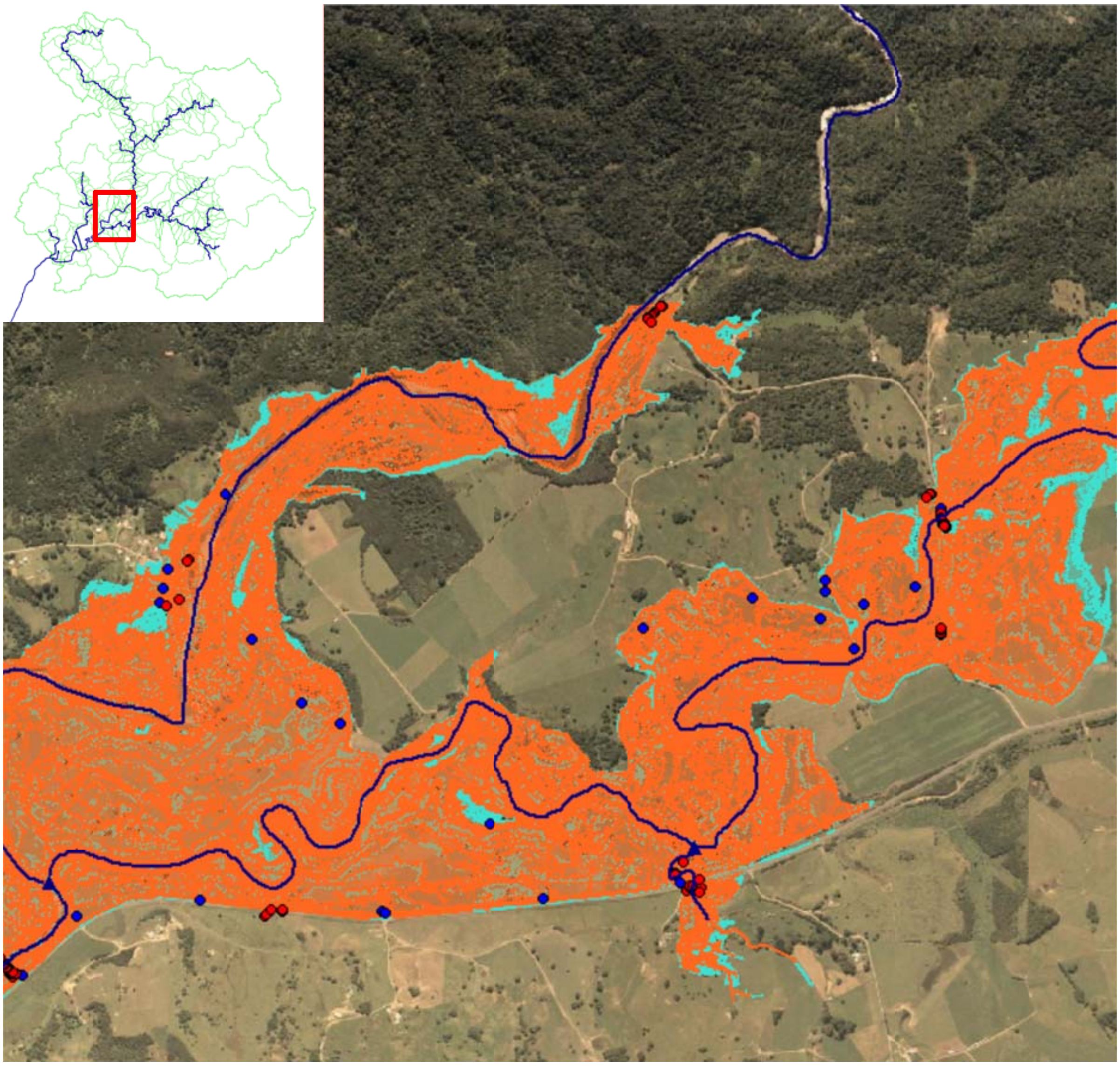
A qualitative comparison was done between the design events and the flood levels surveyed for the events of March 2003 and January 2011. As it is explained in Section 2.2.2, these events present intensities around the 10yr design event. This is shown in Figure 4-3 and Figure 4-4 below.

Figure 4-3 Flood extent against survey levels; lower catchment (middle part)



4 Modelling Results

Figure 4-4 Flood extent against survey levels; lower catchment (upstream end)



A table with the debris points for the 10yr and 100yr with climate change is included in the Appendix B of this report. Note that in many locations the LiDAR level is already higher than the survey level; this makes it hard to judge the quality of the results.

5 Discussion

Important improvements in the model performance, definition of hydraulic and hydrological features allowed us to achieve better model outputs as compared with the 2010 model.

The model was verified for the event of March 1988, however only one flow gauge was available with data at Waipapa, Forest Ranger which is located outside of the LiDAR area, in the upper catchment. This location then was used to verify the hydrological model as level records do not have a reliable datum. The performance of the model in terms of flood level was then compared against the surveyed debris levels for the storms of 2003 and 2011. These storms were close to a 10yr event so the survey levels were compared against the design event instead of the verification event which was closer to a 2yr storm event. The flood levels look generally aceptable in the critical areas, even though there are many points with a questionable datum or plan location.

Regarding the hydrological model, critical and sensitive variables are the base flow and infiltration rate. These variables have an intrinsic relation with the soil moisture. If soil moisture is high, then infiltration rate will be low and base flow higher, and if the soil moisture is low, then infiltration rate will be high and base flow low. All scenarios required a comprehensive hydrological analysis and assumptions in order to estimate these variables properly.

It is important to note that the methodology applied in Waihou catchment was a non-linear reservoir method which does not allow a good representation of the initial losses and uses a constant infiltration rate. However, because the purpose of this modelling work is to calibrate and model big storm events (over 10yrs), the initial losses are not critical as they are consumed by the storm very shortly after the rain starts.

We encourage further analysis in terms of these parameters, creating relations between the variables involved and volume balance from the historical records of level/flow gauges present on NRC catchments, to estimate the effective rain and base flow under different conditions.

On the other hand, it is important to remember that Waihou catchment model is only a theoretical model which has adopted many parameters based on limited data and comparative performance with other catchments, such as base flow, infiltration, non-linear reservoir model coefficients, river roughness and head losses.

Compared with other catchments in the Northland Region, the 1mm/hrs infiltration rate used in this work is very low and reflect uncertainties in the rainfall (probably an underestimation of the total rainfall for that event). This very conservative infiltration rate of 1mm/hr was then adopted for the simulation of the 10yr and 100yr with climate change design events.

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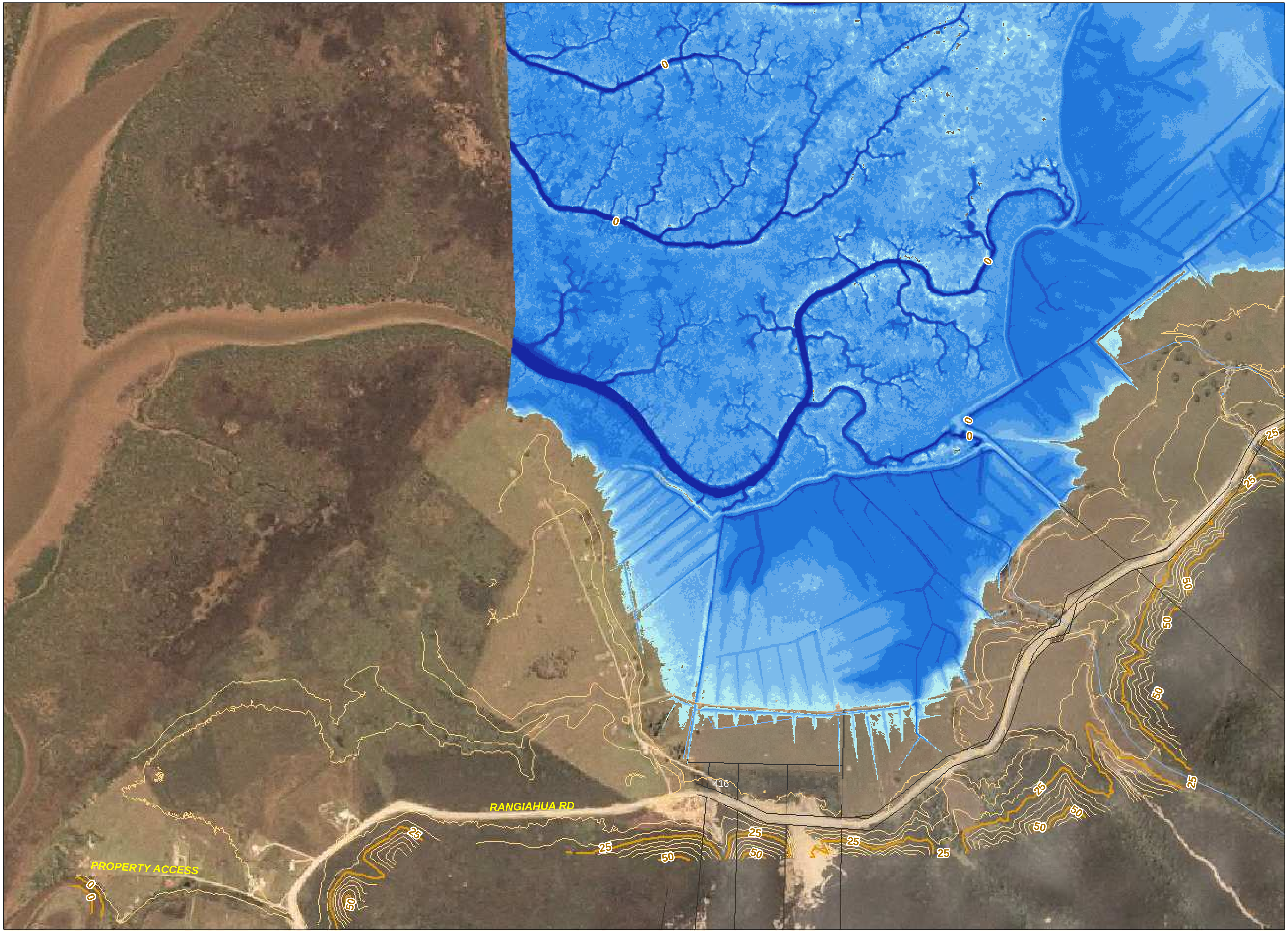
Appendix A Flood Maps



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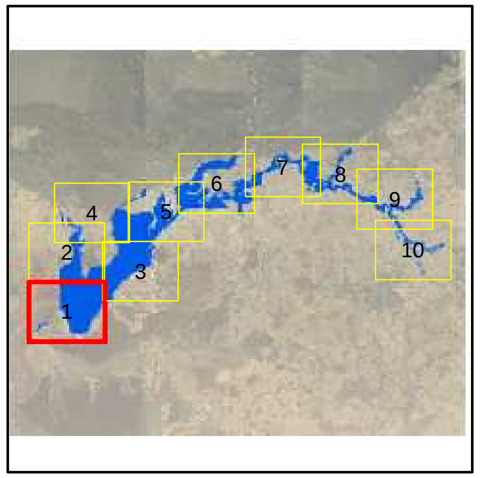

10 year ARI

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- > 3.00

Scale 1:8,000

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The River Care Group

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FLOOD MAPS

Final

WAIHOU RIVER 10 YEAR ARI

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Sheet 1 of 10

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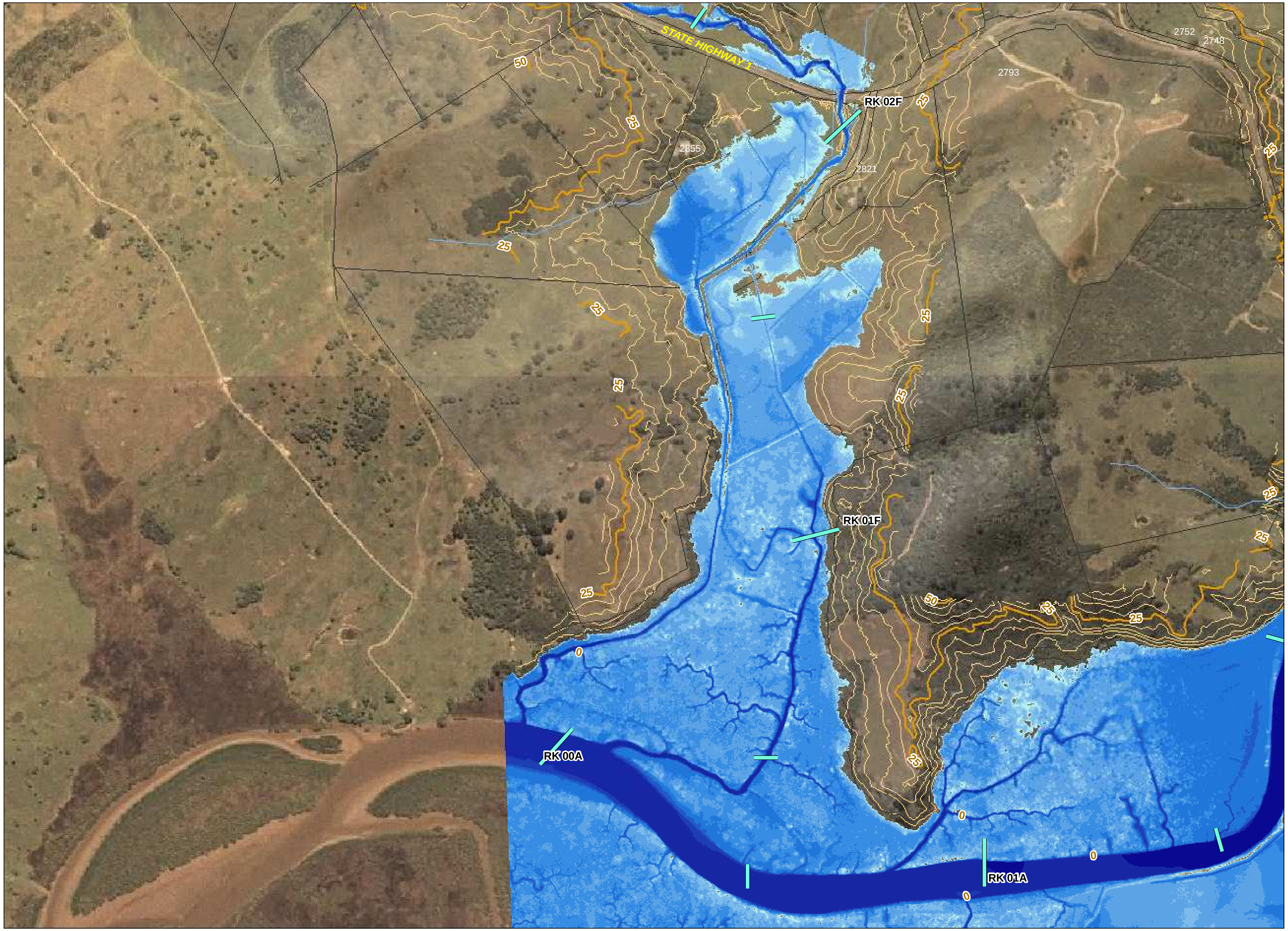

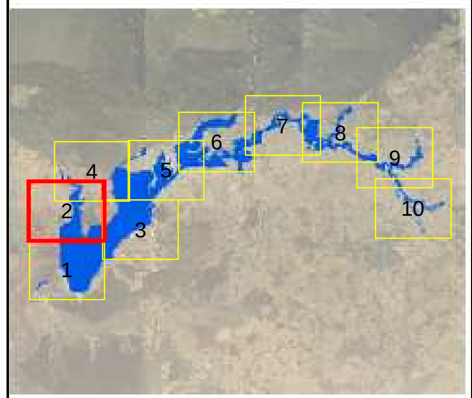

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FLOOD MAPS

Final

WAIHOU RIVER 10 YEAR ARI

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Sheet 2 of 10

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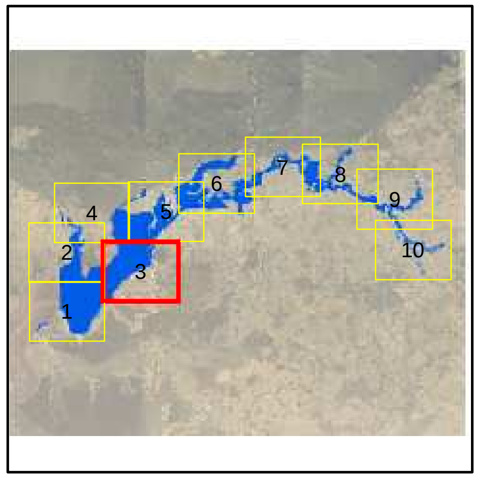

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FLOOD MAPS

Final

WAIHOU RIVER 10 YEAR ARI

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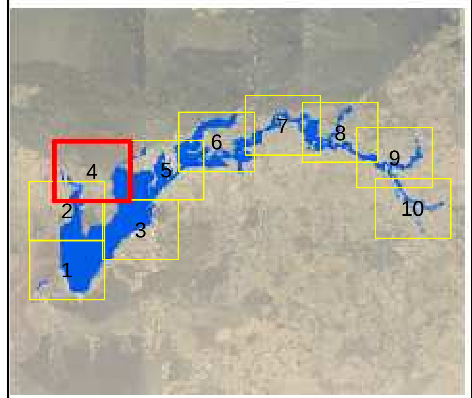

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2.51 - 3.00
> 3.00

Scale 1:8,000

Manaaki Awa

NORTHLAND REGIONAL COUNCIL

FLOOD MAPS

Final

WAIHOU RIVER 10 YEAR ARI

URS

Sheet 4 of 10

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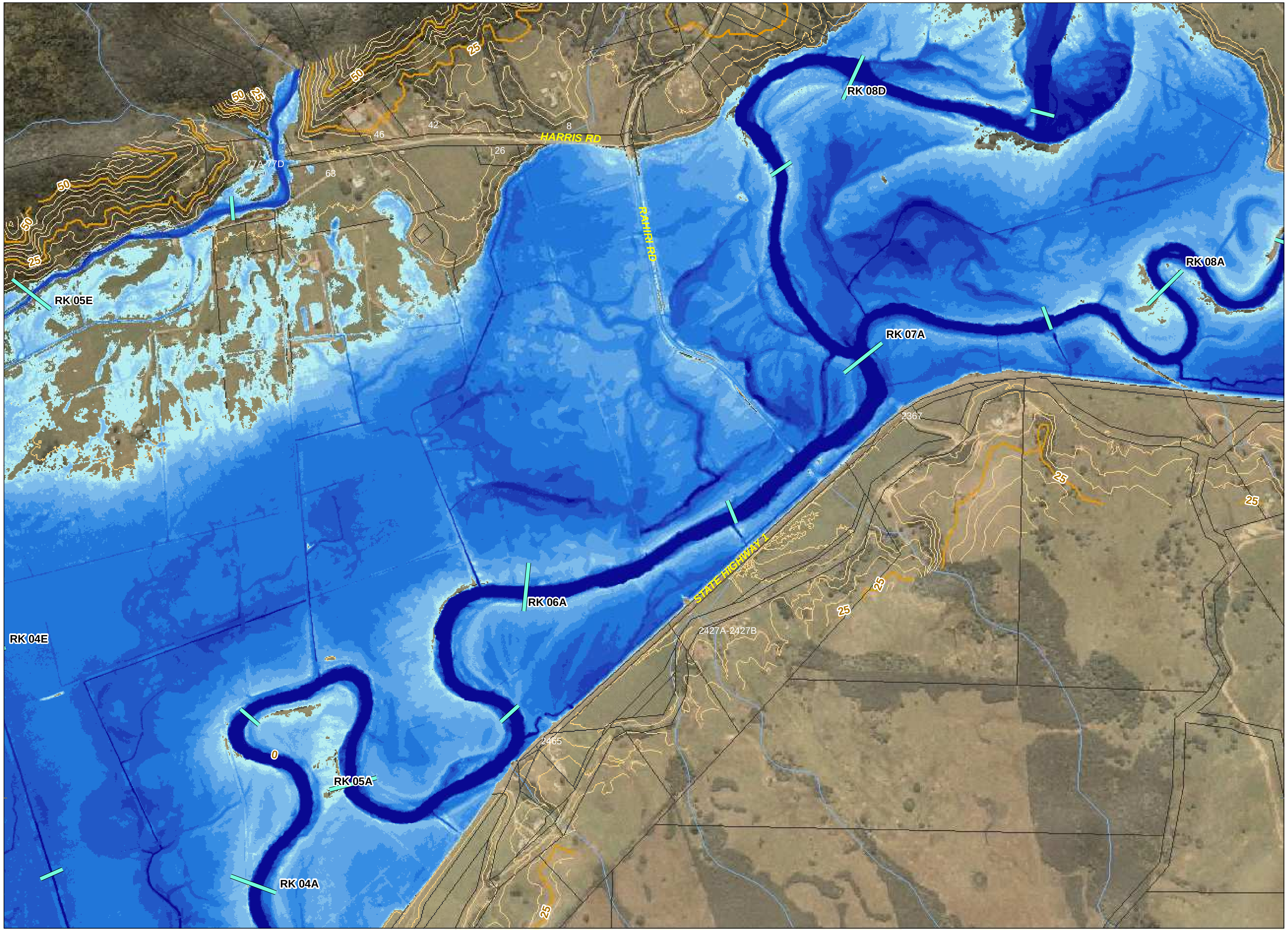

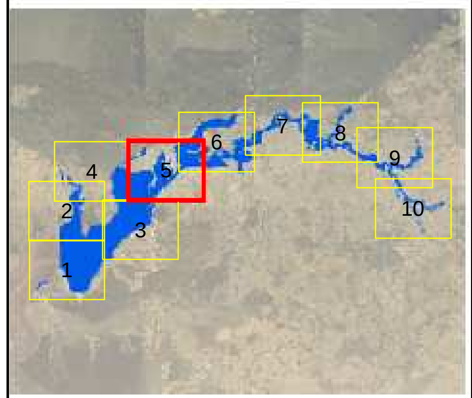

10 year ARI

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- > 3.00

Scale 1:8,000

Manaaki Awa
The River Care Group

NORTHLAND REGIONAL COUNCIL

FLOOD MAPS

WAIHOU RIVER 10 YEAR ARI

Final

URS

Sheet 5 of 10

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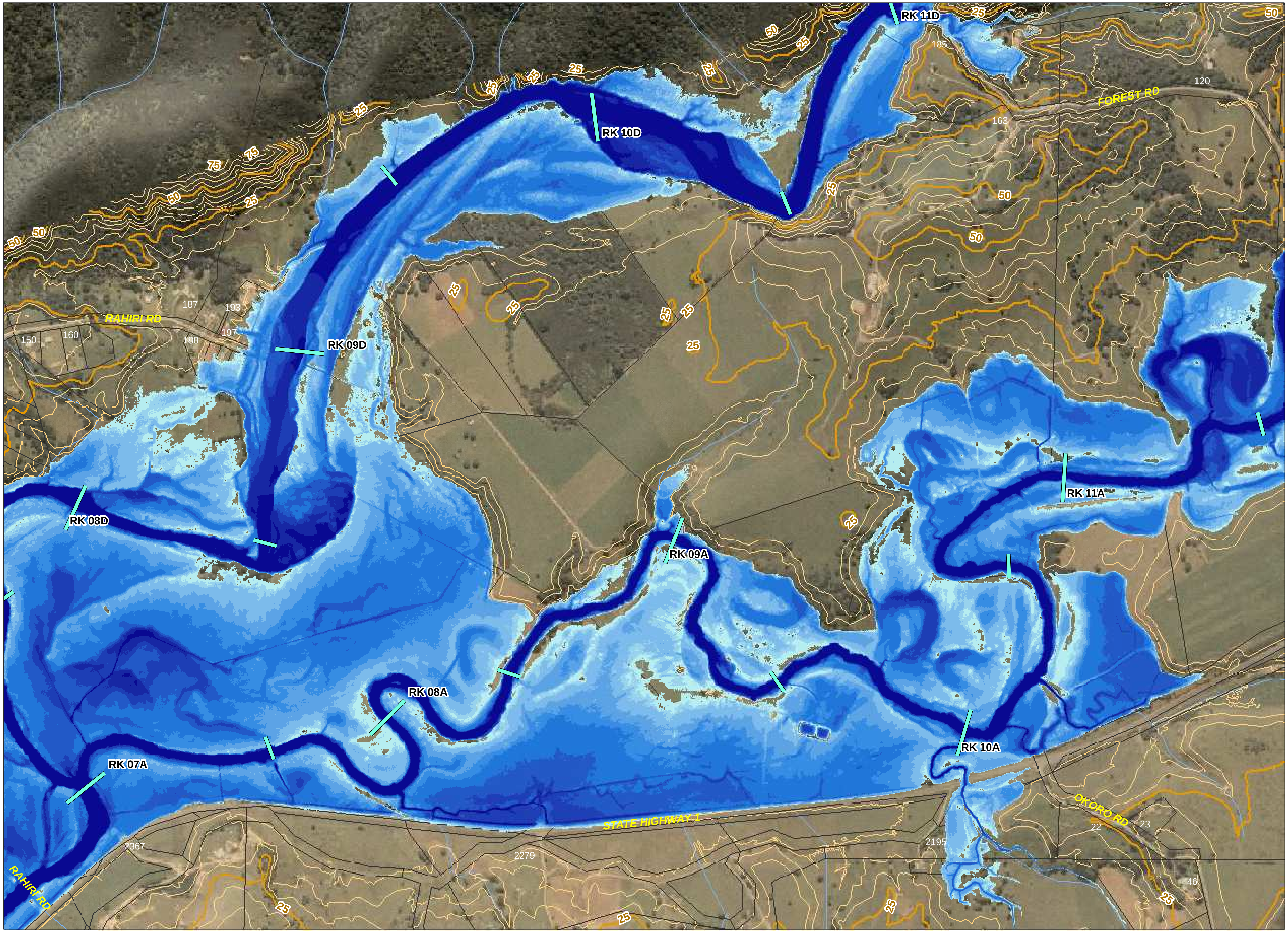

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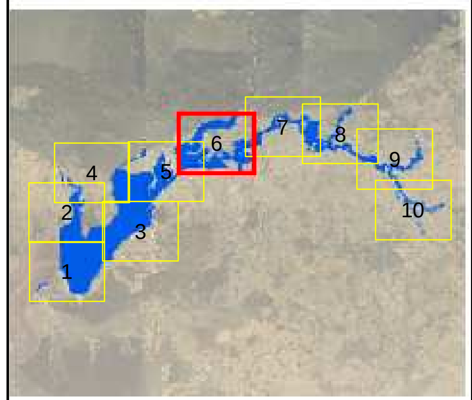

10 year ARI
Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- > 3.00

Scale 1:8,000

Manaaki Awa
The River Care Group

Northland Regional Council

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WAIHOU RIVER 10 YEAR ARI

URS

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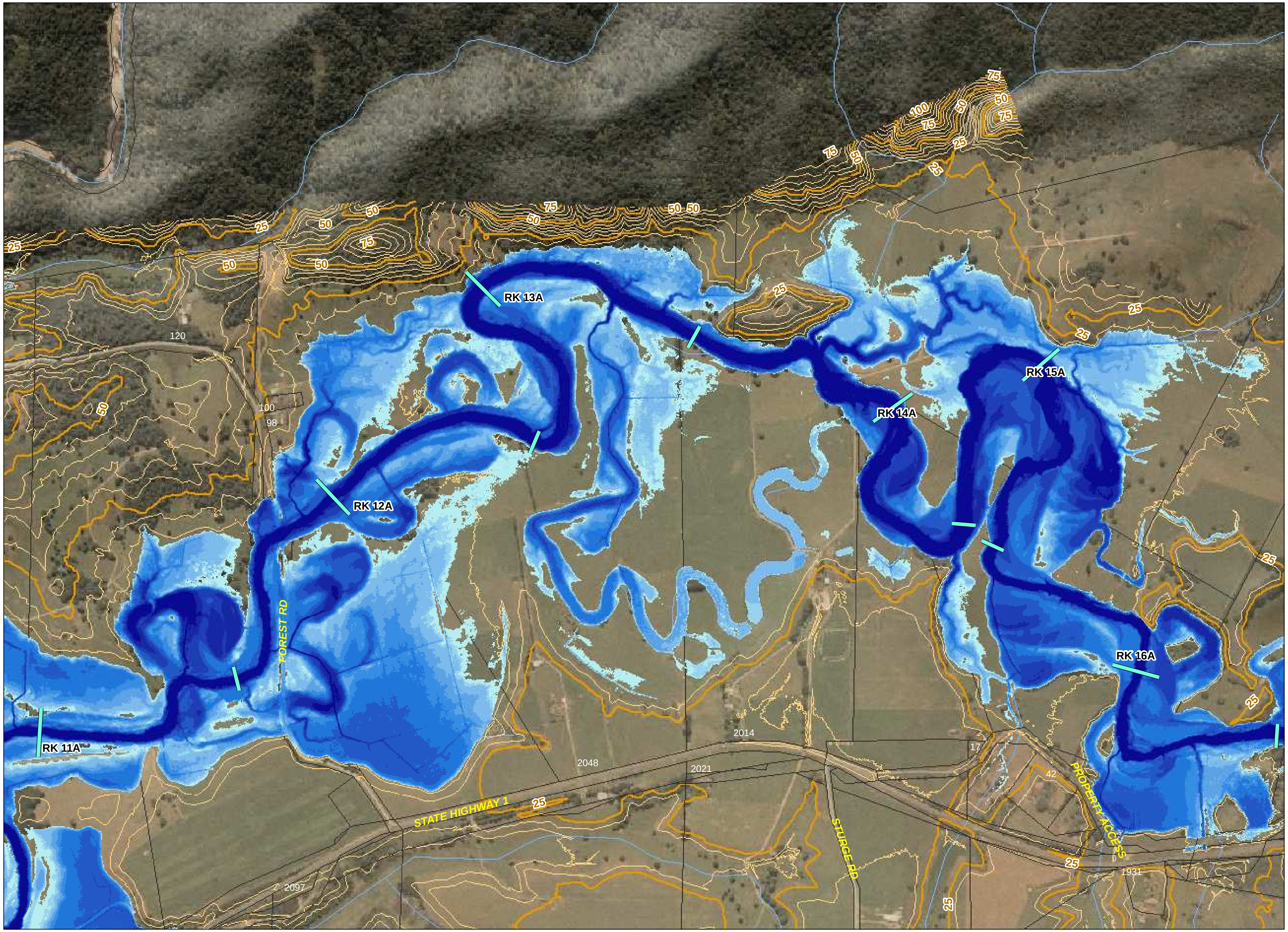

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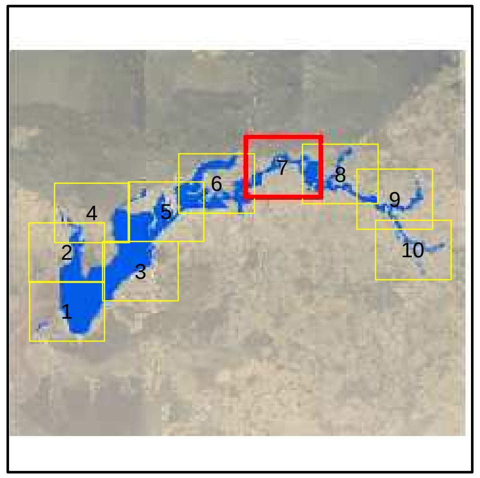

10 year ARI

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
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Scale 1:8,000

Manaaki Awa
The River Care Group

NORTHLAND REGIONAL COUNCIL

FLOOD MAPS

Final

WAIHOU RIVER 10 YEAR ARI

URS

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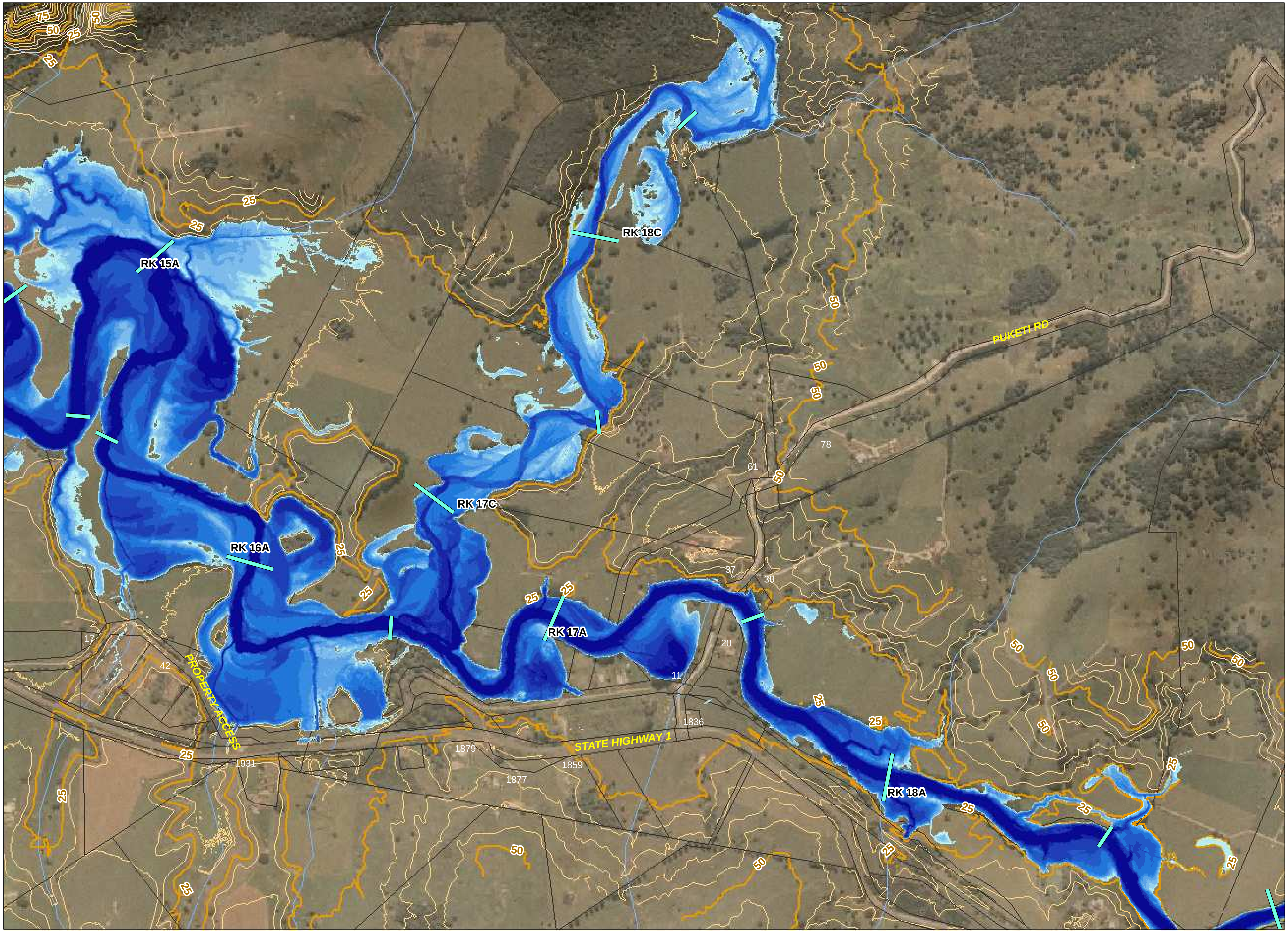

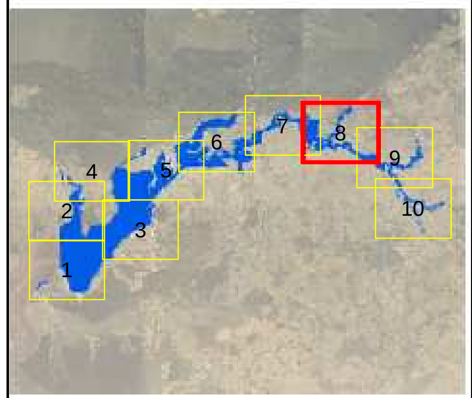

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10 year ARI

Duration 24h

River Kilometre, Rk

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- 0.06 - 0.15
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Scale 1:8,000

Manaaki Awa
The River Care Group

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WAIHOU RIVER 10 YEAR ARI

Final

URS

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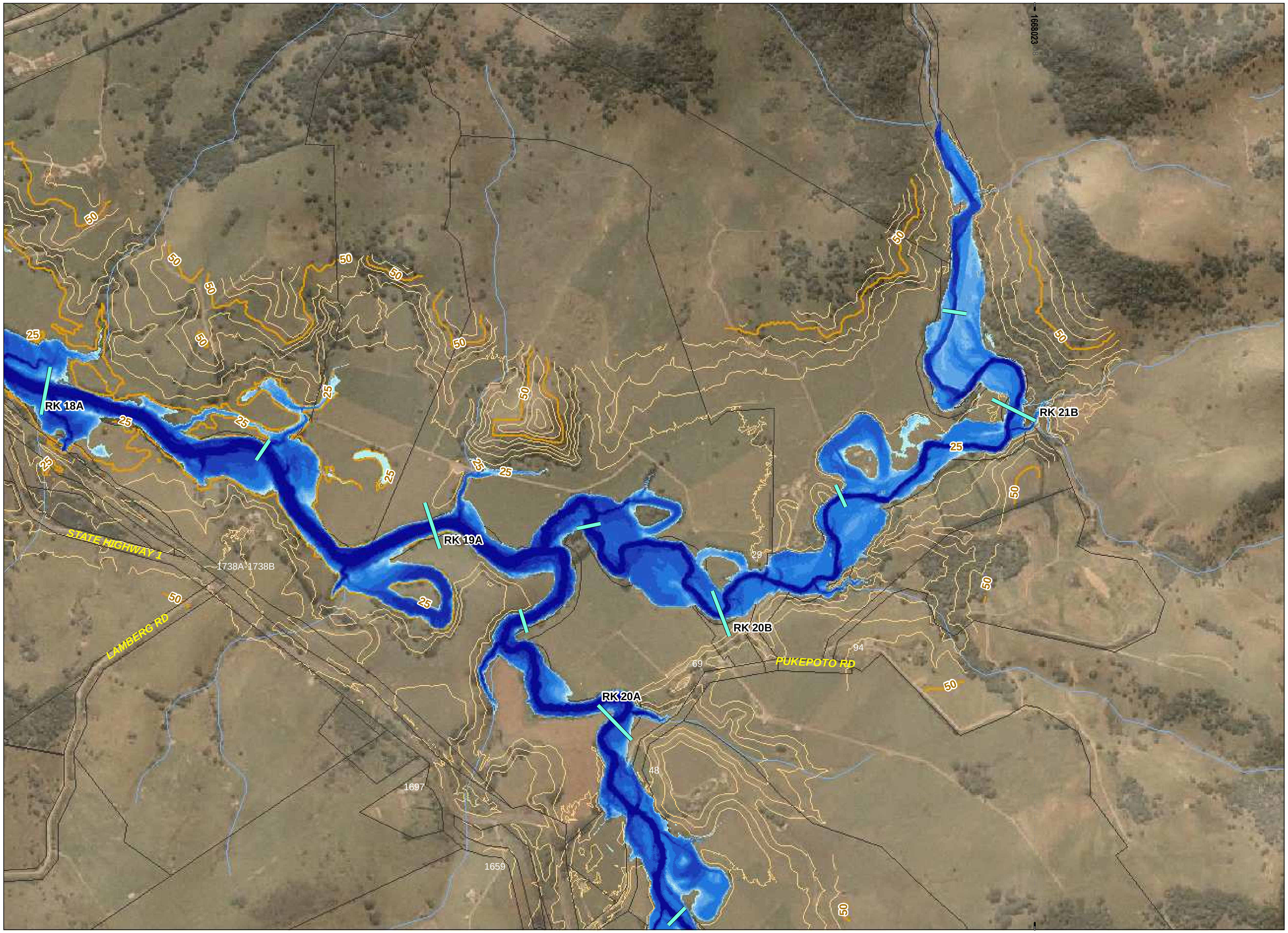

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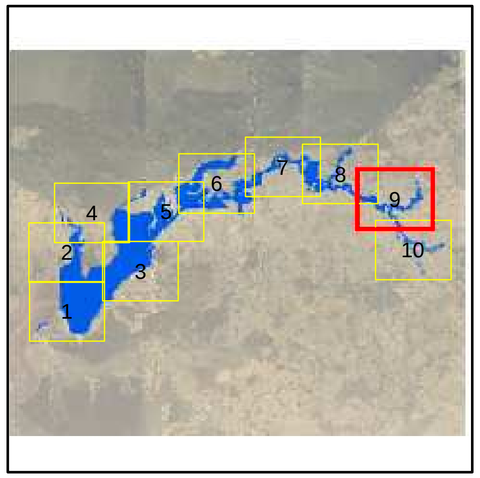

10 year ARI

Duration 24h

River Kilometre, Rk

Flood Depth, m

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Scale 1:8,000

Manaaki Awa
The River Care Group

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WAIHOU RIVER 10 YEAR ARI

URS

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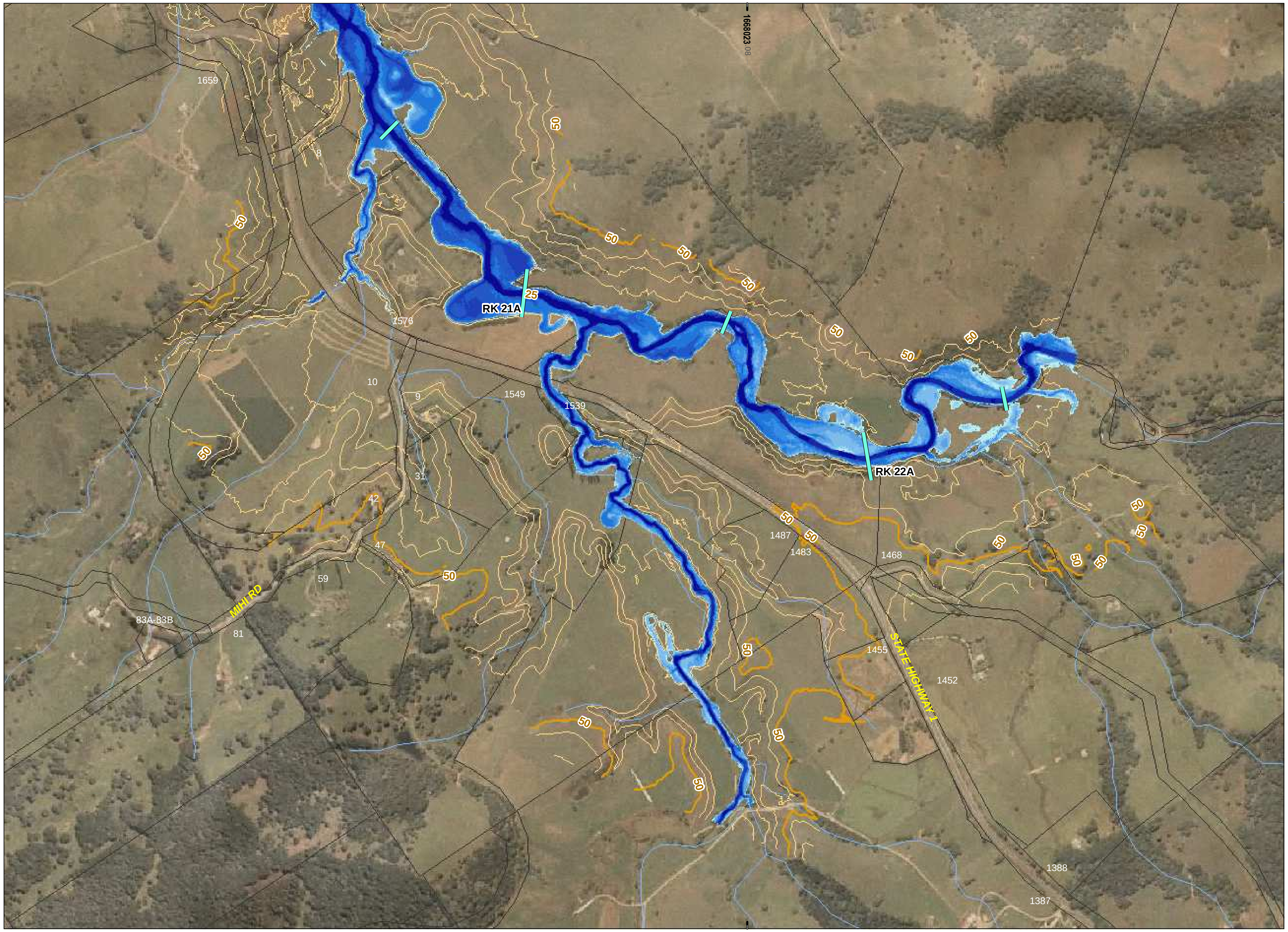

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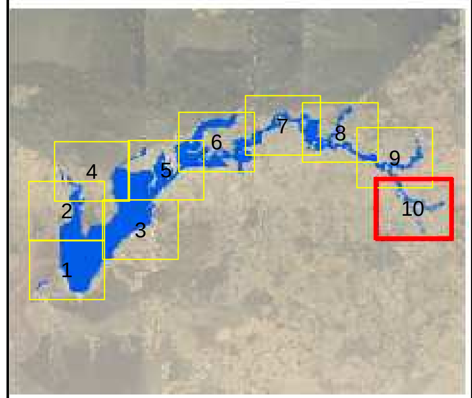

10 year ARI

Duration 24h

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Flood Depth, m

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- 1.01 - 1.50
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- 2.01 - 2.50
- 2.51 - 3.00
- > 3.00

Scale 1:8,000

Manaaki Awa
The River Care Group

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WAIHOU RIVER 10 YEAR ARI

Final

URS

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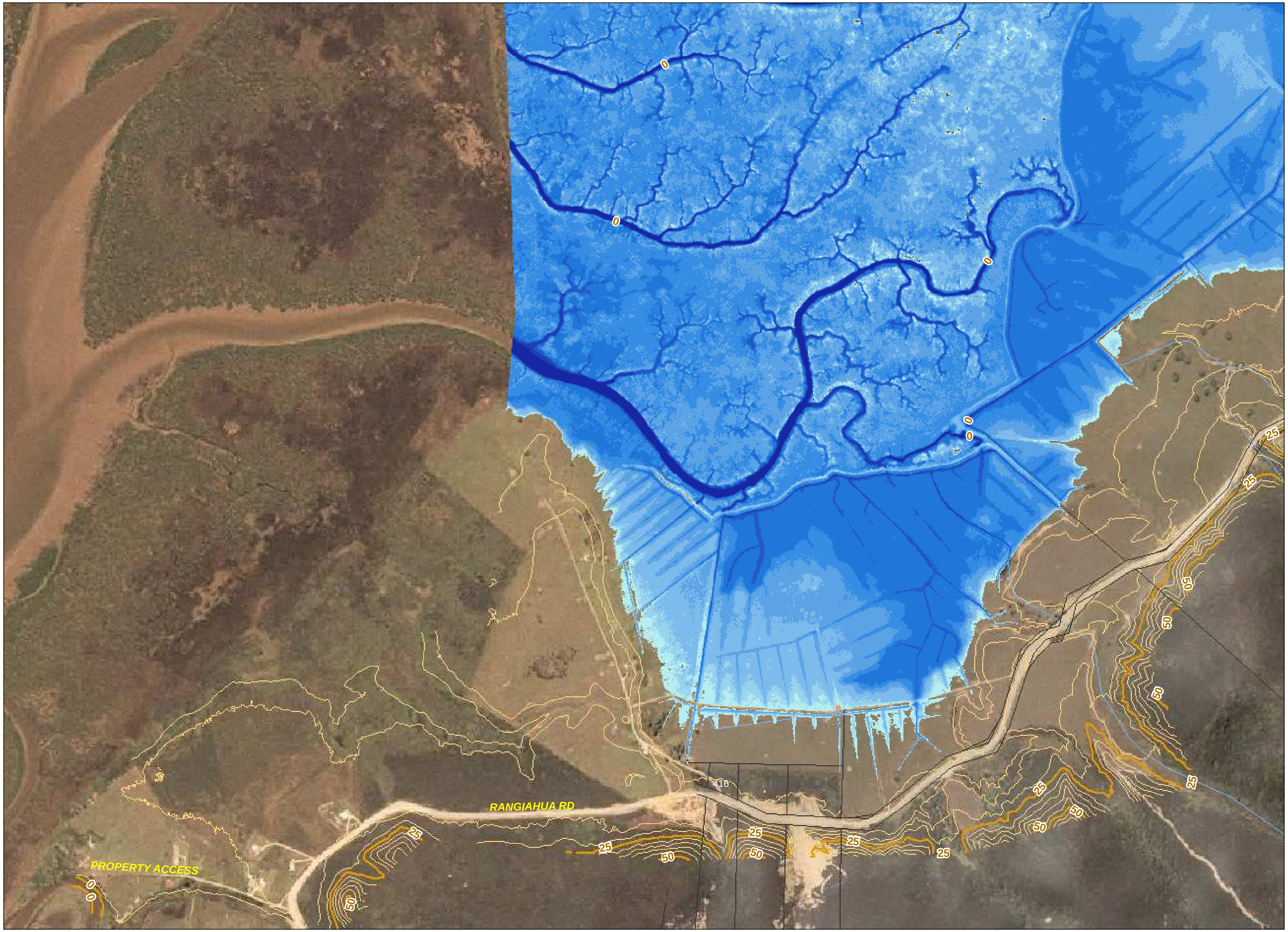

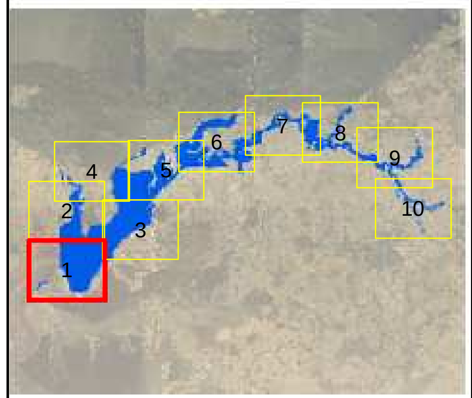

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
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Scale 1:8,000

Manaaki Awa

NORTHLAND REGIONAL COUNCIL

FLOOD MAPS

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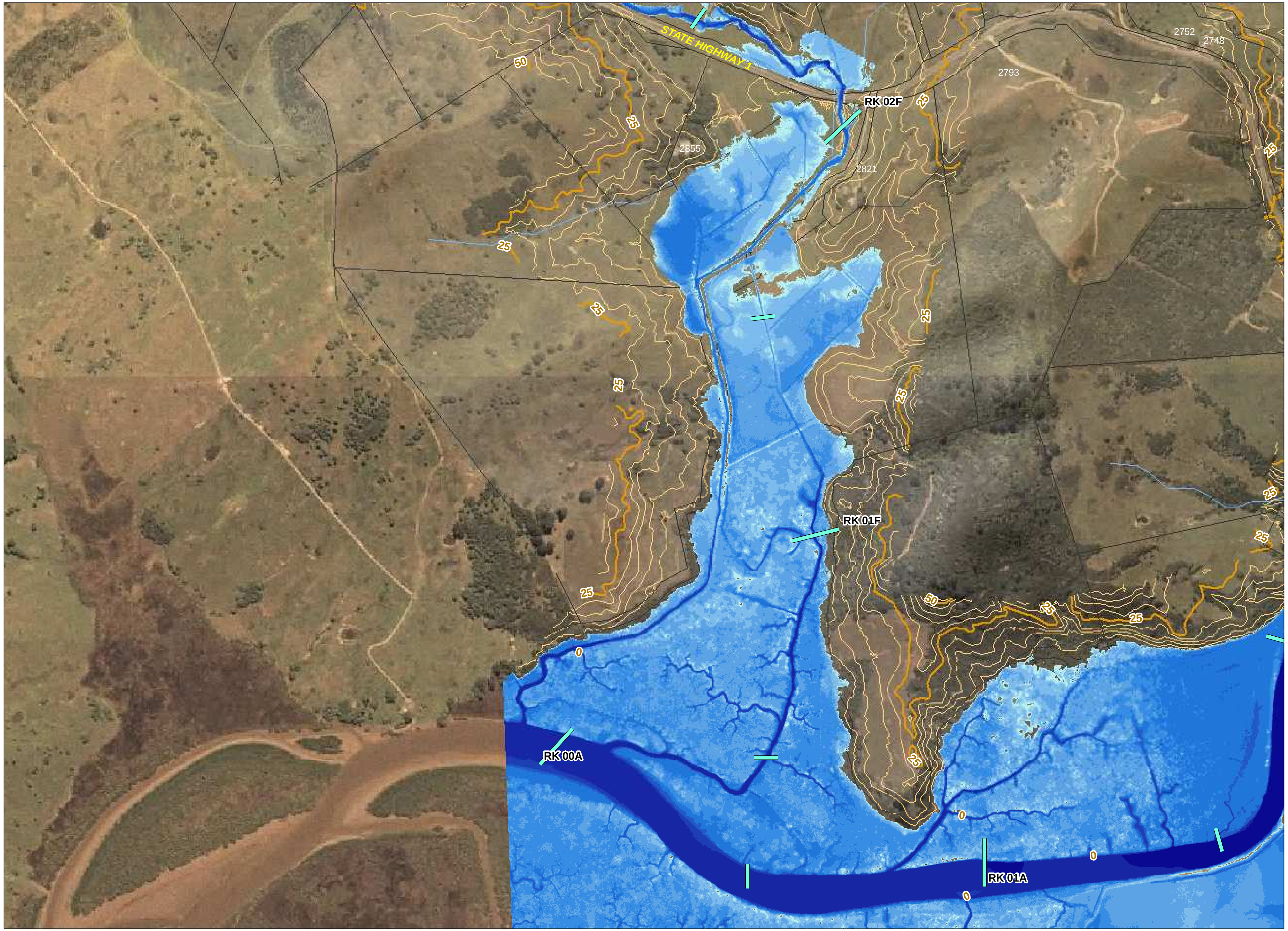
WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

URS

File: 42071138\FloodMaps\07_WAIHOU_RIVER\Flood_Maps.mxd Drawn: FP Approved: JW Date: 24/08/2012 Rev. A A3



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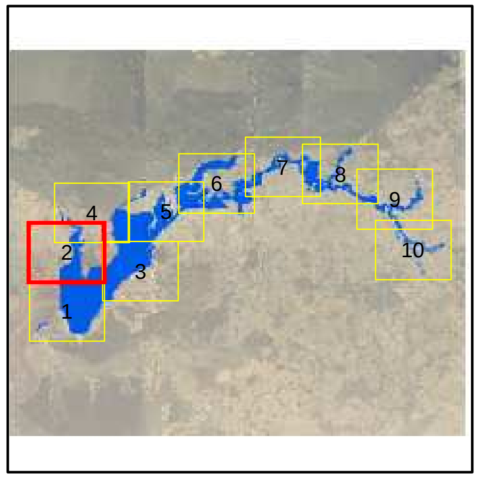

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
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Scale 1:8,000

Manaaki Awa
The River Care Group

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WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

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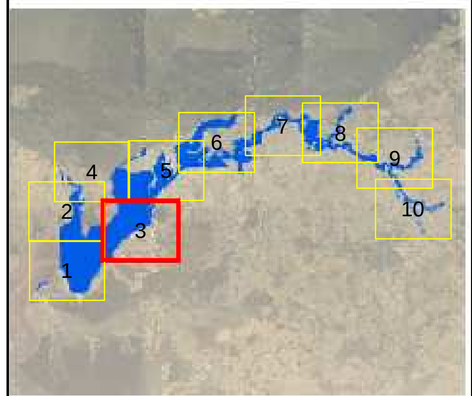

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
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The River Care Group

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WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

URS

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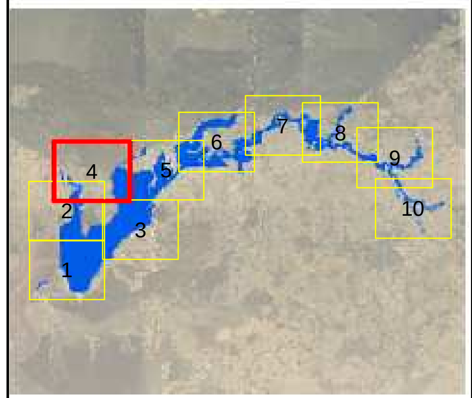

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

Flood Depth, m

- 0.06 - 0.15
- 0.16 - 0.25
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- > 3.00

Scale 1:8,000

Manaaki Awa
The River Care Group

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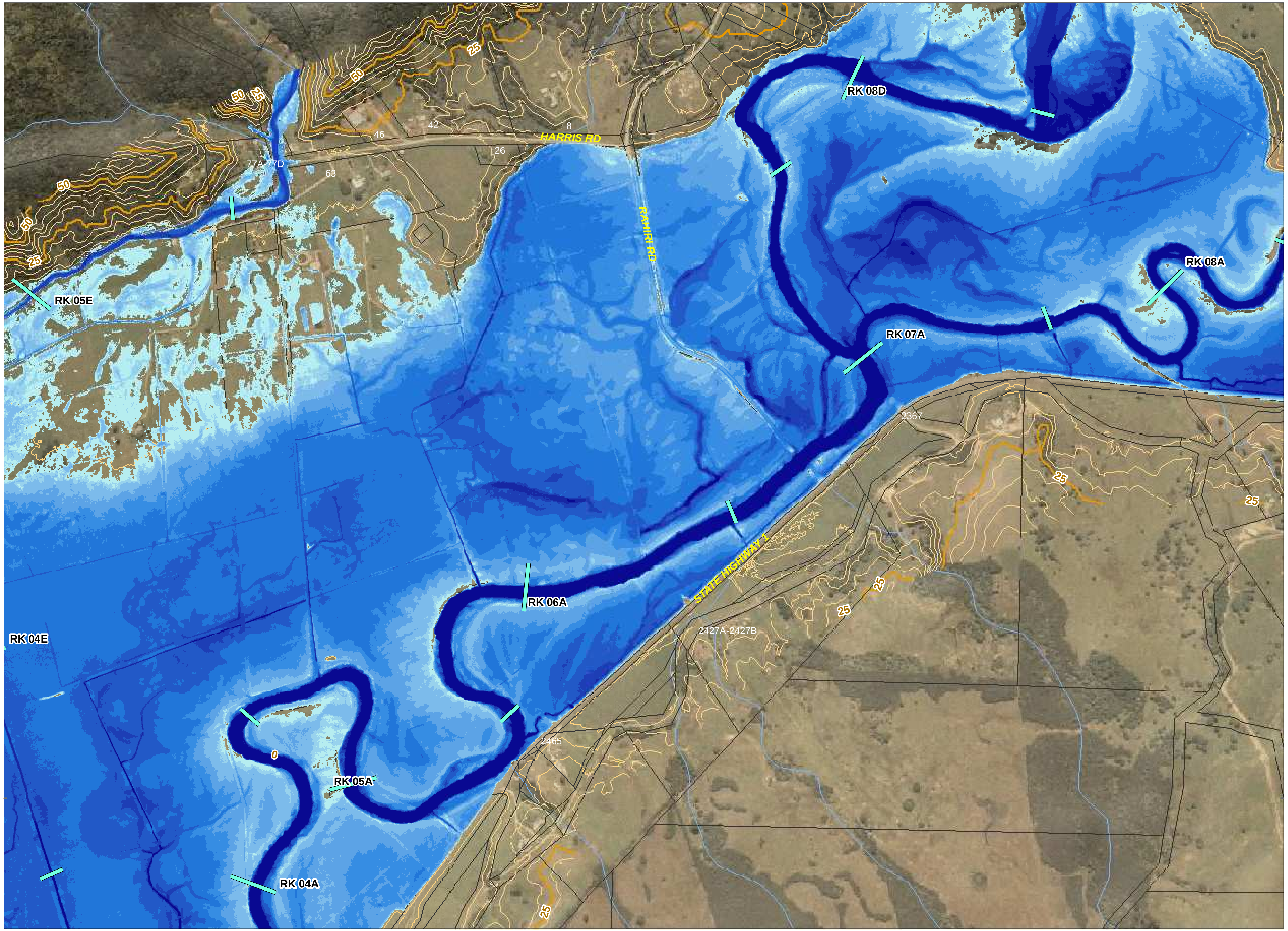

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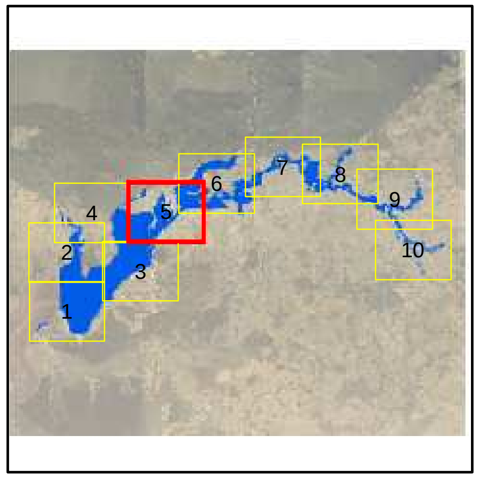

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

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Scale 1:8,000

Manaaki Awa

NORTHLAND REGIONAL COUNCIL

FLOOD MAPS

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WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

URS

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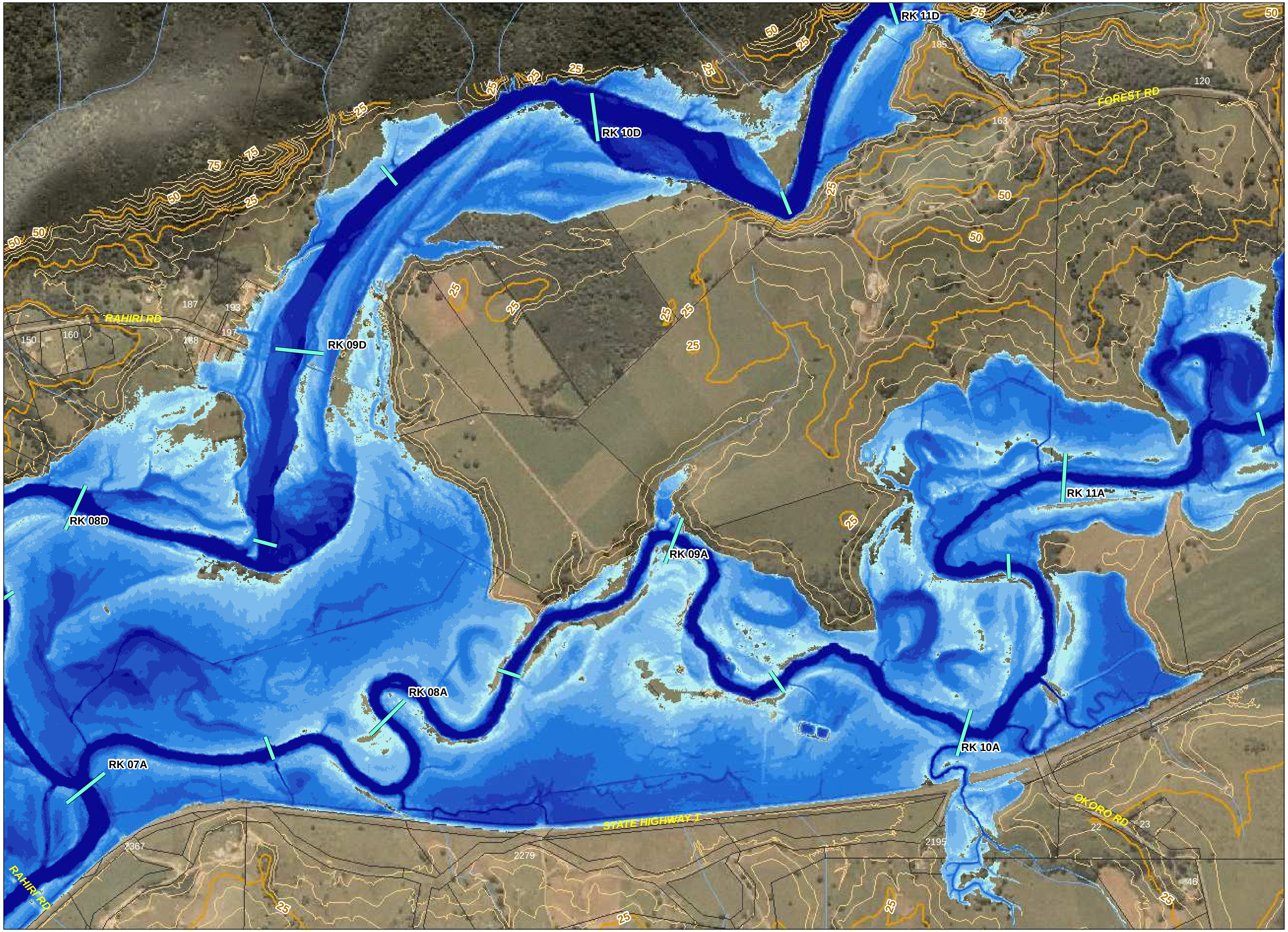

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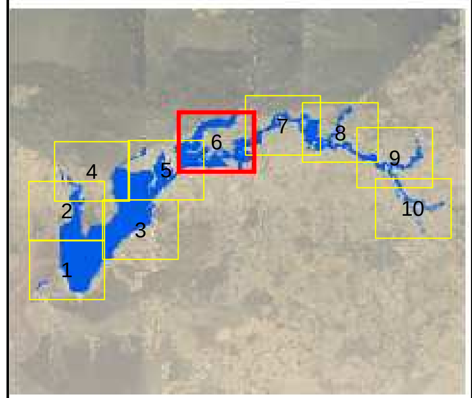

100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

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- 0.06 - 0.15
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Scale 1:8,000

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The River Care Group

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WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

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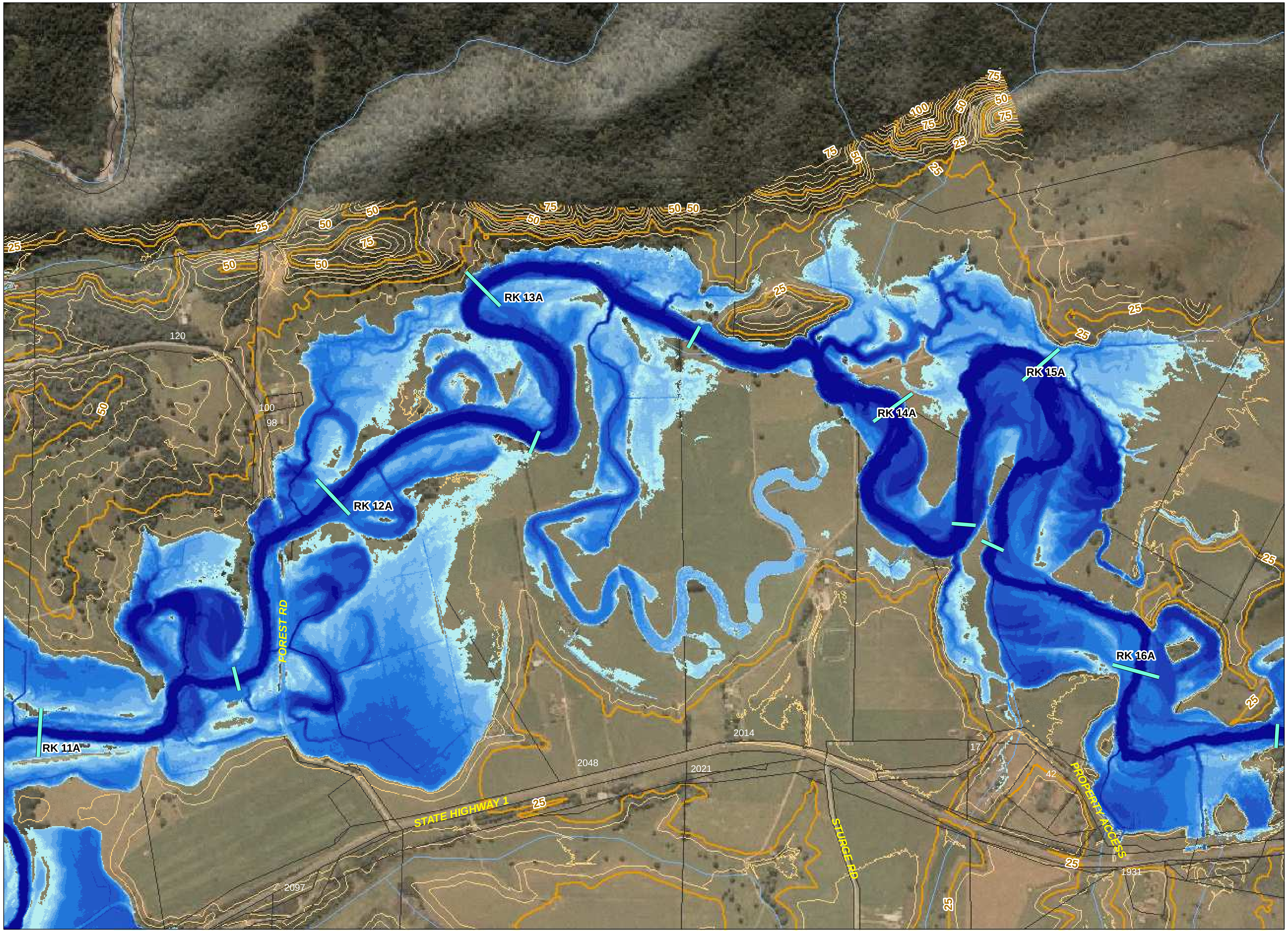

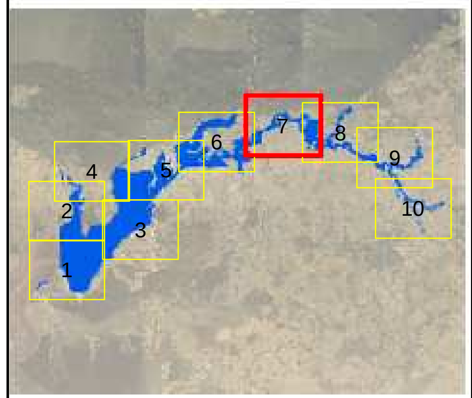

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100 year ARI plus Climate Change

Duration 24h

River Kilometre, Rk

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- 0.06 - 0.15
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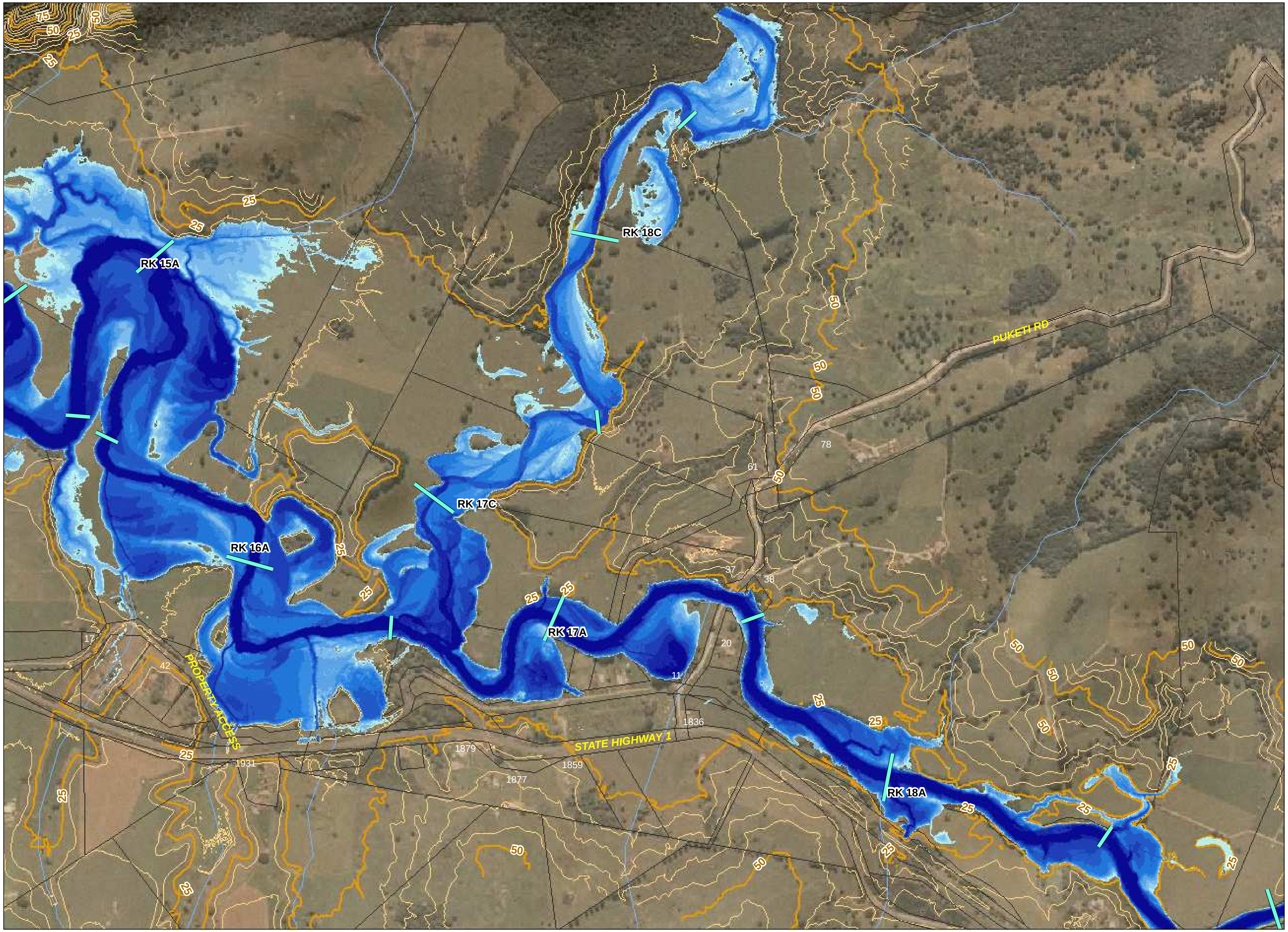

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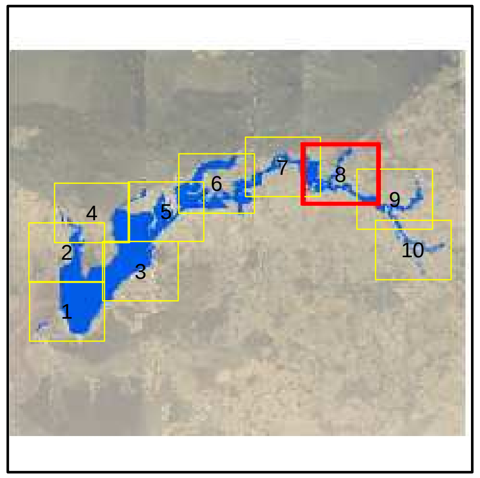

100 year ARI plus Climate Change

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The River Care Group

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Final

WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

URS

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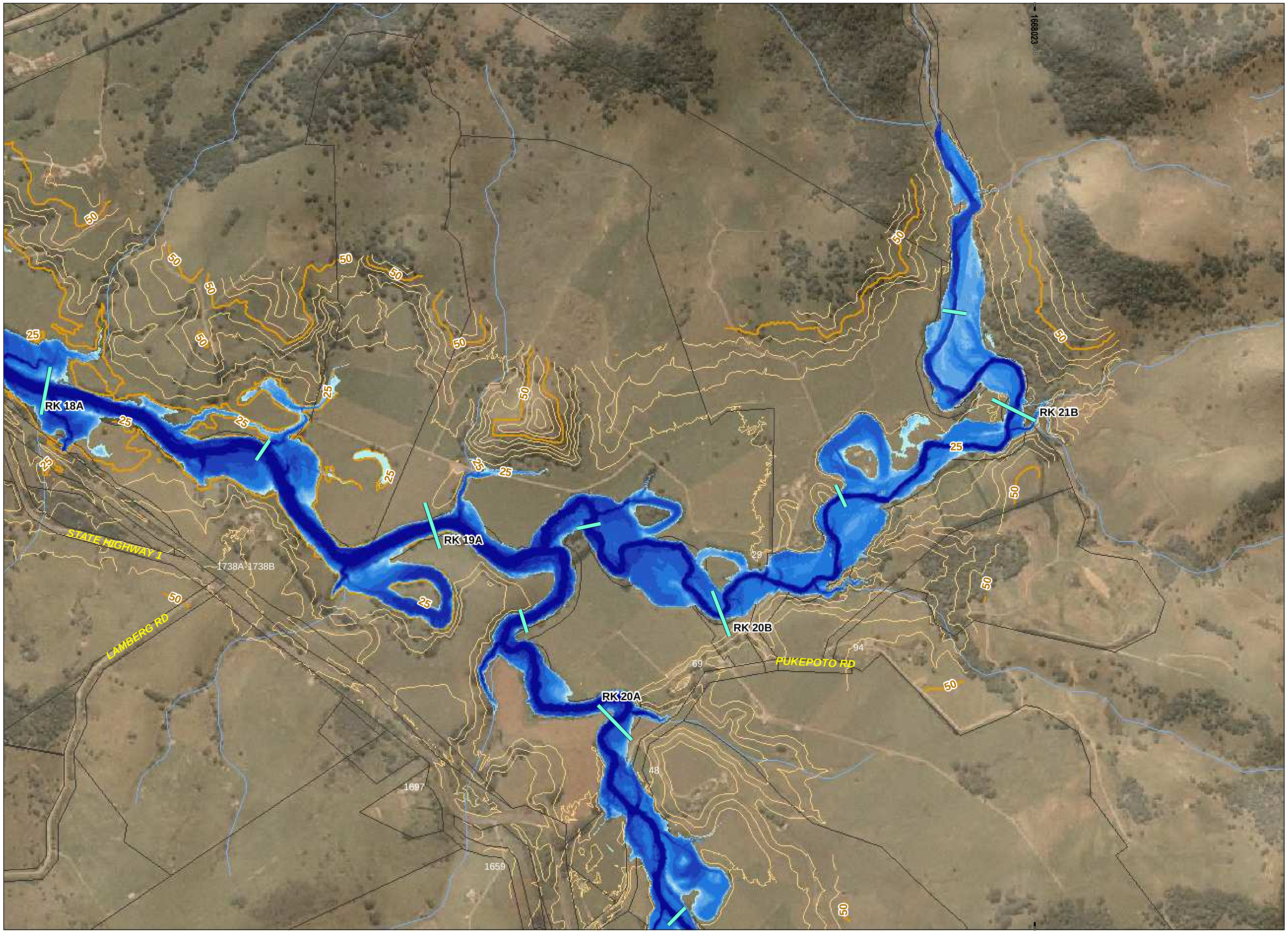

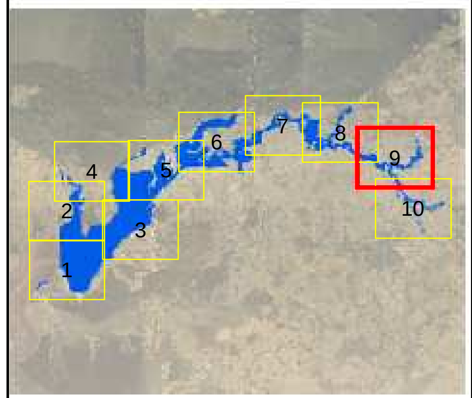

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Manaaki Awa
The River Care Group

NORTHLAND REGIONAL COUNCIL

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WAIHOU RIVER 100 YEAR ARI PLUS CLIMATE CHANGE

Final

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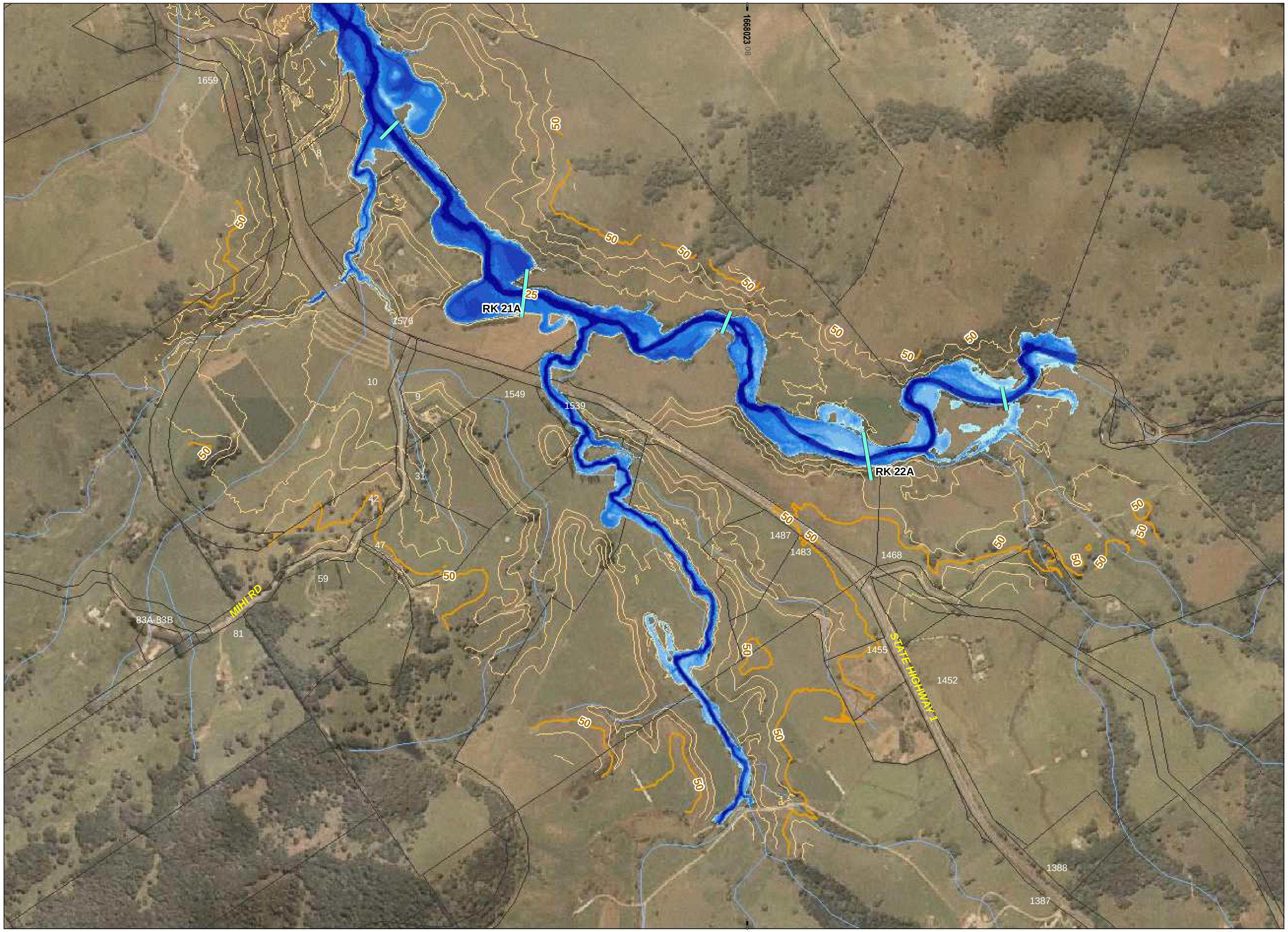

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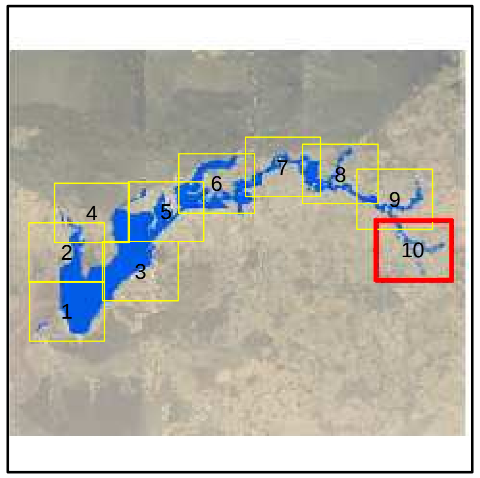

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Appendix B Debris Points Results

Point ID	Srotm Event	X [m NNTM]	Y [m NNTM]	Survey Z [m OTP]	LiDAR Level [m OTP]	10yrs Level [m OTP]	100yrsCC Level [m OTP]	10yrs Depth [m]	100yrsCC Depth [m]
Sur_2003_0001	March 2003	1660297.4	6094100.9	6.809	6.95	7.27	7.89	0.32	0.94
Sur_2003_0002	March 2003	1660194.3	6094197.5	6.722	6.65	7.50	7.98	0.85	1.33
Sur_2003_0003	March 2003	1659961.4	6094398.7	6.625	6.21	6.90	7.64	0.69	1.43
Sur_2003_0004	March 2003	1659919.5	6094722.4	6.7	6.67	7.11	7.85	0.44	1.18
Sur_2003_0005	March 2003	1659979.6	6094794.5	7.003	7.25	7.39	8.06	0.14	0.81
Sur_2003_0006	March 2003	1660053.5	6094817.1	7.161	7.25	7.57	8.41	0.32	1.16
Sur_2003_0007	March 2003	1660084.7	6094847.9	7.521	7.65	7.76	8.50	0.11	0.85
Sur_2003_0008	March 2003	1659212.9	6094170.3	4.662	4.10	5.50	6.05	1.40	1.95
Sur_2003_0009	March 2003	1659204.9	6094117.2	4.633	4.06	5.19	5.95	1.13	1.89
Sur_2003_0010	March 2003	1659237.5	6093766.4	4.561	4.11	4.69	5.65	0.58	1.54
Sur_2003_0011	March 2003	1659099.6	6093842.4	3.888	3.22	4.87	5.48	1.65	2.26
Sur_2003_0012	March 2003	1659096.6	6093879.7	3.894	3.17	4.73	5.51	1.56	2.34
Sur_2003_0013	March 2003	1659067.1	6093998.2	3.893	3.29	4.80	5.58	1.51	2.29
Sur_2003_0014	March 2003	1658736.3	6093667.4	3.486	2.94	4.30	4.98	1.36	2.04
Sur_2003_0015	March 2003	1658655.1	6093637.4	3.49	2.72	4.19	4.95	1.47	2.23
Sur_2003_0016	March 2003	1658542.5	6093831.7	3.305	2.77	4.16	4.95	1.39	2.18
Sur_2003_0017	March 2003	1658542.3	6093831.5	3.404	2.77	4.16	4.95	1.39	2.18
Sur_2003_0018	March 2003	1658565.8	6093863.6	3.389	2.82	4.23	5.01	1.41	2.19
Sur_2003_0019	March 2003	1658595.3	6093659.1	3.361	2.69	4.11	4.89	1.42	2.20
Sur_2003_0020	March 2003	1658914.7	6093752.8	3.703	3.28	4.35	5.14	1.07	1.86
Sur_2003_0021	March 2003	1659563.4	6094348.7	5.569	4.71	6.52	6.92	1.81	2.21
Sur_2003_0022	March 2003	1659968.1	6093798.0	5.656	5.63	6.55	7.11	0.92	1.48
Sur_2003_0023	March 2003	1659964.7	6093795.1	5.757	5.75	6.54	7.11	0.79	1.36
Sur_2003_0024	March 2003	1659624.0	6093472.0	5.43	5.26	5.72	6.24	0.46	0.98
Sur_2003_0025	March 2003	1659310.2	6093069.3	3.642	3.20	3.92	4.50	0.72	1.30
Sur_2003_0026	March 2003	1659042.0	6092796.1	3.403	3.17	3.59	4.08	0.42	0.91
Sur_2003_0027	March 2003	1658702.9	6092730.3	3.042	2.51	3.26	3.82	0.75	1.31
Sur_2003_0028	March 2003	1658691.0	6092746.2	3.095	2.68	3.35	3.84	0.67	1.16
Sur_2003_0029	March 2003	1658423.4	6092756.7	2.978	3.05	3.31	3.92	0.26	0.87
Sur_2003_0030	March 2003	1659257.4	6092832.8	3.465	3.86		4.07		0.21
Sur_2003_0031	March 2003	1658999.9	6092360.4	2.749	2.20	3.09	3.74	0.89	1.54

Sur_2003_0032	March 2003	1658570.2	6092286.5	2.756	2.95	2.95	3.71	0.00	0.76
Sur_2003_0033	March 2003	1658557.2	6092280.9	2.314	2.23	2.89	3.69	0.66	1.46
Sur_2003_0034	March 2003	1660452.1	6094266.4	7.182	6.64	7.78	8.38	1.14	1.74
Sur_2003_0035	March 2003	1660794.7	6094313.0	7.417	7.98	8.29	8.86	0.31	0.88
Sur_2003_0036	March 2003	1661312.7	6094279.6	8.206	7.76	9.36	9.84	1.60	2.08
Sur_2003_0037	March 2003	1661324.7	6094275.4	8.3	8.71	9.37	9.86	0.66	1.15
Sur_2003_0038	March 2003	1661768.1	6094315.5	9.393	8.66	10.27	10.71	1.61	2.05
Sur_2003_0039	March 2003	1662154.1	6094359.8	10.82	11.16		11.49		0.33
Sur_2003_0040	March 2003	1661616.7	6094525.5	6.532	9.16	9.27	9.54	0.11	0.38
Sur_2003_0041	March 2003	1662054.0	6095081.9	11.705	11.27	11.61	11.88	0.34	0.61
Sur_2003_0042	March 2003	1662357.4	6095166.5	11.507	11.15	12.53	13.03	1.38	1.88
Sur_2003_0043	March 2003	1662549.8	6095105.9	11.389	11.54	12.84	13.36	1.30	1.82
Sur_2003_0044	March 2003	1662646.4	6095019.6	12.267	12.34	12.86	13.51	0.52	1.17
Sur_2003_0045	March 2003	1662672.8	6095149.7	12.27	12.18	13.15	14.04	0.97	1.86
Sur_2003_0046	March 2003	1662820.6	6095198.5	12.465	11.40	13.34	14.23	1.94	2.83
Sur_2003_0047	March 2003	1662900.8	6095378.3	12.939	12.48	13.75	14.36	1.27	1.88
Sur_2003_0048	March 2003	1662891.2	6095417.8	13.039	12.43	13.78	14.38	1.35	1.95
Sur_2003_0049	March 2003	1662563.2	6095215.8	12.2	12.44	13.11	13.74	0.67	1.30
Sur_2003_0050	March 2003	1662562.9	6095183.4	12.248	14.50				
Sur_2003_0051	March 2003	1661194.5	6094811.4	7.877	7.13	8.80	9.17	1.67	2.04
Sur_2003_0052	March 2003	1661085.9	6094868.2	8.052	7.58	8.84	9.17	1.26	1.59
Sur_2003_0053	March 2003	1660945.5	6095050.7	8.735	8.55	8.90	9.09	0.35	0.54
Sur_2003_0054	March 2003	1660706.9	6095246.8	9.328	9.37		9.63		0.26
Sur_2003_0055	March 2003	1660694.0	6095190.7	9.288	8.57	9.07	9.49	0.50	0.92
Sur_2003_0056	March 2003	1660684.8	6095154.1	9.17	9.33		9.44		0.11
Sur_2003_0057	March 2003	1660867.4	6095458.2	9.447	9.02	10.08	10.77	1.06	1.75
Sur_2011_1001	January 2011	1662892.4	6095063.7	13.893	12.49	13.50	14.35	1.01	1.86
Sur_2011_1002	January 2011	1662892.9	6095065.6	13.94	12.39	13.51	14.36	1.12	1.97
Sur_2011_1003	January 2011	1662893.4	6095068.5	13.898	12.99	13.51	14.35	0.52	1.36
Sur_2011_1004	January 2011	1662894.5	6095077.5	13.922	13.48	13.53	14.34	0.05	0.86
Sur_2011_1005	January 2011	1662895.1	6095081.4	13.976	13.62		14.35		0.73
Sur_2011_1006	January 2011	1662891.3	6095402.1	12.394	8.60	13.74	14.31	5.14	5.71
Sur_2011_1007	January 2011	1662894.8	6095402.6	12.392	8.60	13.74	14.31	5.14	5.71

Sur_2011_1008	January 2011	1662895.3	6095390.0	12.512	8.60	13.74	14.31	5.14	5.71
Sur_2011_1009	January 2011	1662896.8	6095372.3	12.402	13.03	13.74	14.35	0.71	1.32
Sur_2011_1010	January 2011	1662900.3	6095372.8	12.393	12.73	13.75	14.36	1.02	1.63
Sur_2011_1011	January 2011	1662907.3	6095364.4	14.561	14.07		14.42		0.35
Sur_2011_1012	January 2011	1662906.1	6095366.0	14.45	13.41	13.78	14.42	0.37	1.01
Sur_2011_1013	January 2011	1662903.7	6095366.2	14.138	13.15	13.76	14.40	0.61	1.25
Sur_2011_1014	January 2011	1662864.7	6095460.0	14.634	11.24	13.97	14.60	2.73	3.36
Sur_2011_1015	January 2011	1662859.9	6095457.0	14.538	11.59	13.98	14.61	2.39	3.02
Sur_2011_1016	January 2011	1662854.5	6095450.7	14.417	11.69	13.95	14.59	2.26	2.90
Sur_2011_1017	January 2011	1662107.9	6095991.1	14.316	14.05		15.11		1.06
Sur_2011_1018	January 2011	1662103.4	6095987.4	14.324	13.80	13.98	15.10	0.18	1.30
Sur_2011_1019	January 2011	1662082.8	6095969.4	13.878	13.39	13.88	14.98	0.49	1.59
Sur_2011_1020	January 2011	1662078.3	6095966.2	14.069	13.41	13.85	14.95	0.44	1.54
Sur_2011_1021	January 2011	1662075.4	6095963.9	14.005	13.39	13.83	14.93	0.44	1.54
Sur_2011_1022	January 2011	1662066.0	6095958.9	13.485	12.10	13.79	14.88	1.69	2.78
Sur_2011_1023	January 2011	1662067.1	6095955.0	13.665	12.92	13.80	14.88	0.88	1.96
Sur_2011_1024	January 2011	1662076.4	6095943.5	13.614	12.55	13.82	14.89	1.27	2.34
Sur_2011_1025	January 2011	1664623.8	6094773.8	19.849	20.74				
Sur_2011_1026	January 2011	1664622.6	6094771.6	19.965	20.85				
Sur_2011_1027	January 2011	1662173.0	6094337.3	11.586	11.07	11.24	11.68	0.17	0.61
Sur_2011_1028	January 2011	1662182.0	6094345.4	12.449	10.98	11.21	11.65	0.23	0.67
Sur_2011_1029	January 2011	1662180.2	6094351.8	12.448	11.81				
Sur_2011_1030	January 2011	1662190.2	6094351.0	12.427	9.46	11.21	11.64	1.75	2.18
Sur_2011_1031	January 2011	1662202.7	6094357.8	12.344	10.38	11.21	11.64	0.83	1.26
Sur_2011_1032	January 2011	1662204.5	6094351.7	12.342	10.69	11.23	11.67	0.54	0.98
Sur_2011_1033	January 2011	1662205.5	6094350.6	12.538	10.71	11.23	11.67	0.52	0.96
Sur_2011_1034	January 2011	1662213.2	6094348.5	11.382	11.04	11.26	11.70	0.22	0.66
Sur_2011_1035	January 2011	1662208.9	6094333.3	11.578	10.37	11.27	11.74	0.90	1.37
Sur_2011_1036	January 2011	1662209.9	6094369.8	11.326	12.33				
Sur_2011_1037	January 2011	1662211.2	6094369.7	11.346	12.34				
Sur_2011_1038	January 2011	1662164.6	6094420.5	11.168	10.16	11.06	11.53	0.90	1.37
Sur_2011_1039	January 2011	1662139.7	6094387.8	10.922	10.55	11.05	11.49	0.50	0.94
Sur_2011_1040	January 2011	1662141.5	6094383.6	10.944	10.67	11.05	11.48	0.38	0.81

Sur_2011_1041	January 2011	1660982.3	6094265.8	8.458	7.37				
Sur_2011_1042	January 2011	1660984.7	6094269.9	8.416	7.54				
Sur_2011_1043	January 2011	1661029.0	6094280.5	8.847	8.86				
Sur_2011_1044	January 2011	1661029.8	6094285.3	8.866	8.75		9.09		0.34
Sur_2011_1045	January 2011	1660999.9	6094284.3	8.096	8.82				
Sur_2011_1046	January 2011	1660270.0	6094095.8	7.366	6.29	7.22	7.82	0.93	1.53
Sur_2011_1047	January 2011	1660262.8	6094104.0	7.309	6.50	7.19	7.75	0.69	1.25
Sur_2011_1048	January 2011	1660265.5	6094106.2	7.702	6.53	7.19	7.76	0.66	1.23
Sur_2011_1049	January 2011	1660267.9	6094108.4	7.686	6.51	7.20	7.79	0.69	1.28
Sur_2011_1050	January 2011	1660279.0	6094103.4	7.192	6.57	7.24	7.85	0.67	1.28
Sur_2011_1051	January 2011	1660272.6	6094107.4	7.234	6.72	7.21	7.81	0.49	1.09
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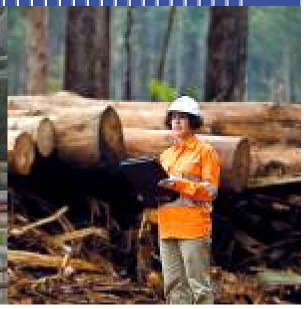
Sur_2011_1053	January 2011	1660254.4	6094118.6	8.7	1.99	7.10	7.64	5.11	5.65
Sur_2011_1054	January 2011	1660252.0	6094123.8	8.716	1.90	7.07	7.62	5.17	5.72
Sur_2011_1055	January 2011	1660246.2	6094132.7	8.732	1.90	7.06	7.60	5.16	5.70
Sur_2011_1056	January 2011	1660243.8	6094130.7	8.725	1.90	7.05	7.57	5.15	5.67
Sur_2011_1057	January 2011	1660232.9	6094142.9	7.705	6.09	7.12	7.71	1.03	1.62
Sur_2011_1058	January 2011	1660235.3	6094145.0	7.679	5.66	7.14	7.74	1.48	2.08
Sur_2011_1059	January 2011	1660236.2	6094146.1	7.007	5.50	7.14	7.76	1.64	2.26
Sur_2011_1060	January 2011	1660233.8	6094148.2	7.202	5.74	7.17	7.80	1.43	2.06
Sur_2011_1061	January 2011	1660175.8	6094200.4	7.291	6.57	7.38	7.89	0.81	1.32
Sur_2011_1062	January 2011	1660164.7	6094212.9	7.121	6.63	7.28	7.89	0.65	1.26
Sur_2011_1063	January 2011	1660176.8	6094226.9	7.506	6.67	7.48	8.07	0.81	1.40
Sur_2011_1064	January 2011	1660180.6	6094222.6	7.578	6.66	7.50	8.07	0.84	1.41
Sur_2011_1065	January 2011	1660138.5	6094251.9	7.669	6.60	7.20	7.92	0.60	1.32
Sur_2011_1066	January 2011	1660136.0	6094255.3	7.636	6.65	7.22	7.92	0.57	1.27
Sur_2011_1067	January 2011	1660134.3	6094257.6	7.553	6.76	7.23	7.92	0.47	1.16
Sur_2011_1068	January 2011	1660763.9	6095273.6	9.815	8.52	9.44	9.90	0.92	1.38
Sur_2011_1069	January 2011	1660763.0	6095270.5	9.71	8.58	9.44	9.90	0.86	1.32
Sur_2011_1070	January 2011	1660737.4	6095162.3	9.604	8.65	9.11	9.50	0.46	0.85
Sur_2011_1071	January 2011	1660702.5	6095144.7	9.133	7.39	9.10	9.47	1.71	2.08
Sur_2011_1072	January 2011	1660703.3	6095143.9	9.174	7.42	9.09	9.46	1.67	2.04
Sur_2011_1073	January 2011	1659176.2	6094741.0	10.779	9.10	11.21	11.77	2.11	2.67

Sur_2011_1074	January 2011	1659182.0	6094732.2	11.013	9.10	11.17	11.67	2.07	2.57
Sur_2011_1075	January 2011	1659913.2	6094765.1	7.493	7.33		7.86		0.53
Sur_2011_1076	January 2011	1659912.7	6094766.4	7.549	7.36		7.86		0.50
Sur_2011_1077	January 2011	1659926.6	6094752.3	7.414	6.63	7.27	7.92	0.64	1.29
Sur_2011_1078	January 2011	1659917.2	6094750.8	7.464	6.82	7.19	7.86	0.37	1.04
Sur_2011_1079	January 2011	1658462.9	6092734.1	3.391	2.29	3.17	3.78	0.88	1.49
Sur_2011_1080	January 2011	1658499.1	6092732.7	3.624	2.38	3.19	3.82	0.81	1.44
Sur_2011_1081	January 2011	1658367.4	6092789.7	3.4	3.35		3.76		0.41
Sur_2011_1082	January 2011	1658367.2	6092788.9	3.498	3.32		3.76		0.44
Sur_2011_1083	January 2011	1658370.3	6092790.3	4.796	3.38		3.78		0.40
Sur_2011_1084	January 2011	1658373.1	6092791.9	4.787	3.79				
Sur_2011_1086	January 2011	1658374.1	6092794.1	3.333	4.29				
Sur_2011_1087	January 2011	1658379.3	6092791.3	3.643	4.91				
Sur_2011_1088	January 2011	1658380.5	6092788.8	3.637	4.86				
Sur_2011_1089	January 2011	1658381.5	6092786.5	3.628	4.80				
Sur_2011_1090	January 2011	1658783.1	6092756.5	3.74	3.09	3.38	3.94	0.29	0.85
Sur_2011_1091	January 2011	1658788.1	6092757.8	3.654	3.14	3.39	3.96	0.25	0.82
Sur_2011_1092	January 2011	1659039.7	6092785.2	3.763	3.21	3.46	3.99	0.25	0.78
Sur_2011_1093	January 2011	1659033.4	6092782.2	3.751	3.33	3.45	3.98	0.12	0.65
Sur_2011_1094	January 2011	1659205.3	6092903.3	3.76	3.20	3.75	4.22	0.55	1.02
Sur_2011_1095	January 2011	1659202.1	6092898.6	3.462	3.45	3.74	4.22	0.29	0.77
Sur_2011_1096	January 2011	1659211.0	6092899.2	3.766	3.70	3.77	4.26	0.07	0.56
Sur_2011_1097	January 2011	1659213.6	6092901.5	3.676	3.85		4.26		0.41
Sur_2011_1098	January 2011	1659650.6	6093504.1	5.707	5.08	5.72	6.14	0.64	1.06
Sur_2011_1099	January 2011	1659624.5	6093475.0	5.158	4.98	5.72	6.22	0.74	1.24







URS New Zealand Limited
URS Centre, 13-15 College Hill
Auckland 1011
PO Box 821, Auckland 1140New Zealand

T: 64 9 355 1300
F: 64 9 355 1333

www.urscorp.co.nz